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BULLETIN OF THE TORREY BOTANICAL CLUB

VOL. 88, No. 4, pp. 215–259 JULY, 1961

Changing Concepts of Photosynthesis[1]

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"Are not gross Bodies and Light convertible into one another, and may not Bodies receive much of their activity from the Particles of Light which enter their Composition? . . . The Changing of Bodies into Light, and Light into Bodies, is very conformable to the Course of Nature, which seems delighted with Transmutations." Sir Isaac Newton, *Opticks*, (1721).

Paper presented as part of a
special symposium on
FUNDAMENTAL DEVELOPMENTS IN PLANT GROWTH
in conjunction with the A.A.A.S. meetings

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[1] This article is based, in part, on a colloquium given by the author at Harvard University on April 18, 1960. The experimental work in the author's laboratory was aided by grants from the National Institutes of Health and the Office of Naval Research.

[The BULLETIN for May–June 1961 (88: 143–214) was issued September 4, 1961.]

As one surveys the history of photosynthesis, now near the end of its second century, one finds fresh relevance in the admonition of Priestley (1777), whose work "on different kinds of air" marked the beginning of our knowledge of this process. Priestley wrote in 1777: "This is a new and wide field of experiments and speculation, and a premature attachment to hypothesis is the greatest obstruction we are likely to meet with in our progress through it. . . . Speculation is a cheap commodity. New and important facts are most wanted, and therefore of most value."

This survey will include some of the trails of discovery and interpretation that first placed and later displaced oxygen evolution and CO_2 assimilation as the "cornerstones" of photosynthesis. Some current ideas will be abandoned and some old ideas will be recalled from their contemporary obscurity and given new emphasis in the light of the findings of the last six years, when photosynthesis ceased to be a "vital" process of carbon assimilation, and was shown to be a series of biochemical events that can be reproduced independently of the structure of the intact cell.

My principal aim is to trace, without going into details, the change in the concepts of photosynthesis from the first one—that of planetary ventilation, to the current one—of energy conversion. The emphasis will be on those experimental facts that lead to a unified concept of photosynthesis as an energy conversion process in which CO_2 assimilation and oxygen evolution are not general but only special manifestations. Although this concept has already passed the test of predicting certain experimental findings in and beyond conventional photosynthesis of plants and bacteria, it still remains tentative in some particulars and is presented here in a spirit that disavows a "premature attachment to hypothesis."

The treatment of literature will be selective rather than comprehensive. More exhaustive reviews of recent work are available elsewhere (Jagendorf 1958, Arnon 1960, 1961 a, b).

1. **The Principle of Vegetation.** There are few areas in biology which illustrate as vividly as photosynthesis how our knowledge of the living world depends on advances in physics and chemistry. Photosynthesis in green plants involves an exchange of gases, CO_2 is absorbed and oxygen is evolved. Since this gas exchange cannot be detected by direct visual observation, the discovery of photosynthesis had to await the development of methods for identifying and measuring gases. Without these methods photosynthesis remained a secret, despite the long association of mankind with growing plants and crops, and defied detection in all ages by the keenest intellects and the most gifted observers of Nature.

The futility of the search for the fundamental principle of plant life prior to the development of methods for studying gases may be illustrated by two examples. Aristotle assigned to green leaves the function of providing shade to tender shoots in the intense summer sun—a thought which is

supposed to have occurred to him when he contemplated on a hot day in a vineyard the purpose of the rather large leaves of the grapevine. He considered that plants obtain all their "food" in a predigested form from the soil, which acts as a huge stomach for the plant. He thought that because of this terrestrial stomach, the nutrition of the plant, unlike that of the animal, leaves no excreta.

About two thousand years later, in the seventeenth century, the Flemish physician and chemist, van Helmont, sought to penetrate the secret of vegetation, in what was probably the first recorded quantitative experiment in biology. He planted in 200 pounds of weighed dry soil, a willow branch weighing five pounds, protected the container from dust by a cover, and watered, as needed, with rain water. In five years' time the willow had increased in weight by 164 pounds, although the soil in the container, when dried and weighed again, showed a loss of only 2 ounces. Van Helmont concluded from this experiment that "164 pounds of the roots, leaves, wood and bark, which constituted the tree, appeared to have sprung from the water alone," and consequently, that water is the principle of vegetation, the source of all plant substance. It is an ironic touch of history, that the then unknown photosynthetic gas exchange obscured completely the meaning of this excellent experiment to van Helmont, who coined the word *gas* (from "chaos") and is remembered today as the early founder of pneumatic chemistry (Holmyard 1931).

The secret of photosynthesis could not be penetrated by merely observing and contemplating Nature without the aid of special knowledge and laboratory devices. The most acute powers of observation and reasoning had never revealed the fact that the green leaf is a busy chemical factory manufacturing the bulk of plant substance. This fact was an effective reminder to natural philosophers of an earlier day that the most fundamental laws of Nature cannot be learned by direct observation but must be explored with the aid of "artificial" laboratory experiments under controlled conditions.

2. **Photosynthesis and Planetary Ventilation.** The chain of discoveries which led to a knowledge of what we now call photosynthesis began in 1772 when Joseph Priestley found that "plants instead of affecting the air in the same manner with animal respiration, reverse the effect of breathing, and tend to keep the atmosphere sweet and wholesome, when it is become noxious in consequence of animals either living and breathing, or dying and putrefying in it" (Priestley 1774, p. 86). Priestley was able to make his momentous discovery by using special devices for measuring gases or, more specifically, changes in the composition of air. The devices he used were a mouse and a burning candle. In putrid air, unless green plants were present, a mouse would suffocate and die and the flame of a burning candle would become extinguished. ("Dephlogisticated air" or oxygen as a pure gas was discovered by Priestley, and independently by Scheele in Sweden, a few years later.)

Priestley's discovery aroused tremendous interest in the world of science and learning of the 18th century. Its impact was primarily not on chemistry or botany but on what we would call today public health. Priestley's work provided the first rational explanation why the air of our planet remained healthful despite the continuous breathing of man and animals for millions of years. This appreciation of Priestley's findings is reflected in the citation read by Sir John Pringle when, as President of the Royal Society, he awarded to Priestley the Copley Medal in 1773. "From these discoveries," the citation read, "we are assured, that no vegetable grows in vain, but that, from the oak of the forest to the grass in the field, every individual plant is serviceable to mankind; if not always distinguished by some private virtue, yet making a part of the whole, which cleanses and purifies our atmosphere" (Reed 1949).

It may be of interest to recall in passing that Priestley's discovery was also hailed by his friend, Benjamin Franklin, who hoped that it might prove relevant to the American scene. He wrote to Priestley, "that the vegetable creation should restore the air which is spoiled by the animal part of it looks like a rational system. . . . I hope that this will give check to the rage of destroying trees that grow near houses, which has accompanied our late improvements in gardening, from an opinion of their being unwholesome" (Priestley 1774, p. 95). Regrettably, a look at some contemporary American suburban developments gives reason to think that Franklin's hope has not been fulfilled to this day.

The enthusiasm which greeted Priestley's discovery was followed by doubts. Other investigators, notably Scheele in Sweden, failed to repeat his experiments and Priestley himself, when he returned to this subject six years later, was also unable to repeat his earlier findings. "The experiments of this year (1778)," he admitted, "were unfavorable to my former hypothesis. For whether I made the experiments with air injured by respiration, the burning of candles, or any other phlogistic process, it did not grow better but worse; and the longer the plants continued in the air, the more phlogisticated it was" (Priestley 1779).

Despite these contradictions, Priestley remained cautiously optimistic as to the validity of his original discovery. He said, "Upon the whole, I still think it probable that the vegetation of healthy plants, growing in situations natural to them, has a salutary effect on the air in which they grow. For one clear instance of the amelioration of air in these circumstances, should weigh against a hundred cases in which the air is made worse by it" (Priestley 1779).

But the contradictions remained and beclouded the significance of Priestley's original findings which won him world acclaim six years earlier. The puzzle was cleared up by the Dutch physician Ingenhousz, who was then attached as court physician to the Imperial Household of the Empress Maria

Theresa in Vienna. Ingenhousz was "struck with admiration" at Priestley's original findings and perceived that "the discovery of Dr. Priestley, that plants thrive better in foul air than in common and dephlogisticated air, and that plants have a power of correcting bad air, has thrown a new and important light upon the arrangement of this world" (cf. Reed 1949).

In 1779 Ingenhousz obtained leave to go to London and investigate further the discovery of Priestley that had now become uncertain. He tells that on arriving "I disengaged myself from the noise of the metropolis, and retired to a small villa, where I was out of the way of being interrupted by any body in the contemplation of Nature." There he made one of the most important discoveries in natural science by carrying out, as he reported, "500 experiments, all of which were made in less than three months, having begun them in June, and finished them in the beginning of September, working from morning till night."

He described his discovery in these words: "I observed that plants not only have a faculty to correct bad air in six or ten days, by growing in it, as the experiments of Dr. Priestley indicate, but that they perform this important office in a compleat manner in a few hours; that this wonderful operation is by no means owing to the vegetation of the plant, but to the influence of the light of the sun upon the plant, . . . is far from being carried on constantly, but begins only after the sun has for some time made his appearance above the horizon, . . . is more or less brisk in proportion to the clearness of the day, . . . diminishes towards the close of the day, and ceases entirely at sun-set [and] . . . that this office is not performed by the whole plants, but only by the leaves and the green stalks that support them." He also noted, "that the sun by itself has no power to mend air without the concurrence of plants."

It is of interest to experimental science to recall the philosophy of research that guided this accomplished physician, at the peak of his professional and worldly success to this engrossing and brilliant effort. He wrote that "natural knowledge can make but a very slow progress in the hands of those who have not patience and assiduity enough in pursuing one and the same object, till they discover some things undiscovered before; or till they find that the difficulty of the undertaking surpasses their abilities" and that "detached experiments may indeed be very useful when a sufficient number is collected to draw some conclusions from them; but, without pursuing methodically the same object, discoveries are to be expected by mere chance, and are even sometimes overlooked" (cf. Reed 1949).

The discovery of Ingenhousz provided the first, experimentally documented role for light in the newly emerging knowledge of photosynthesis. Light was shown to be the agent that enables green plants to transform

"bad air" or "fixed air" into pure, "vital" or "dephlogisticated air". In the 1780's, when Lavoisier founded the "new chemistry" and its new nomenclature, the action of light could be expressed as transforming carbonic acid into oxygen.

3. **Emergence of a Concept of Plant Nutrition.** In 1796, Ingenhousz published an *Essay on the Food of Plants and Renovation of Soils* in which he adopted the new chemical concepts and terminology of Lavoisier. Ingenhousz was now able to interpret correctly the full significance of his earlier findings, and to explain the contradictions of Priestley and Scheele. This he did in these words: "I was fortunate enough to discover the true reason why plants did sometimes correct bad air, and sometimes made it worse, which reason was never so much as even suspected either by Dr. Priestley or by Scheele; . . . I discovered in the summer 1779, that all vegetables are incessantly occupied in decomposing the air in contact with them, changing a great portion of it into fixed air, now called carbonic acid. . . . I found that the roots, flowers, and fruits are incessantly employed in this kind of decomposition, even in the middle of sunshine; but that the leaves and green stalks alone cease to perform this operation, during the time the sun, or an unshaded clear daylight shines upon them: during which time, they throw out a considerable quantity of the finest vital air (oxygen)". This was the first clear and correct statement of plant respiration and its relation to photosynthesis and may be regarded as the foundation of modern concepts of plant nutrition.

As regards the green parts of the plant, Ingenhousz suggested that they absorb from "carbonic acid in the sunshine, the carbon, throwing out at that time the oxygen alone, and keeping the carbon to itself as nourishment" (Ingenhousz 1796). This was the end of the restricted view that the remarkable behavior of plants in light was important mainly because it ventilated our planet and the beginning of the hypothesis that the function of light in photosynthesis was the splitting of CO_2, with a resultant liberation of O_2 and the retention of "C" for forming plant substance. This hypothesis was embraced and fortified by Ingenhousz' contemporaries, Senebier and de Saussure, and was destined to remain unchallenged for well over a hundred years.

The classical work of de Saussure (1804) closed the gap which still obscured the understanding of the gross chemical events in photosynthesis. De Saussure showed that water is a reactant in this process. His experiments demonstrated that, while assimilating CO_2 "plants had increased their dry weight by a quantity greater than they could obtain from the elements of carbonic acid" (p. 225). From this, he concluded that "plants appropriate the oxygen and hydrogen of water, by making water lose its liquid state. But this assimilation (of water) is pronounced only when plants assimilate carbon at the same time" (p. 236).

If water was a reactant in photosynthesis, was it possible that the oxygen evolved in this process had come from a decomposition of water rather than of CO_2? De Saussure's answer to this question was no, because, "in no case do plants decompose water directly by assimilating its hydrogen and eliminating its oxygen in gaseous form; plants exhale oxygen only through the decomposition of carbonic acid" (p. 237).

4. **Chemosynthetic and Photosynthetic Bacteria.** Few hypotheses in biology seemed as secure with the passage of time, and had a more tenacious hold on the thinking of biologists for over a century, as the one suggested by Ingenhousz—that the function of light in photosynthesis is the splitting of CO_2, with a resultant liberation of O_2 and the retention of "C" for forming plant substance. In the 19th century this hypothesis grew to the stature of a fixed principle which served to divide all living organisms into two main groups: green plants that lived by using radiant energy for the assimilation of CO_2, and organisms without chlorophyll that were incapable of using radiant energy for CO_2 assimilation and could therefore subsist only by consuming the organic substances formed by the photosynthetic group.

So firm was the conviction that only green plants could form organic substances by assimilating CO_2 that in the 19th century the term "assimilation" became established in several European languages, to describe what is now called photosynthesis. Assimilation, i.e., the formation of organic substances from CO_2, was believed to be peculiar to green plants whereas metabolism, i.e., the utilization of organic substances formed by plants, was understood to occur in both plants and animals (Hansen 1882).

This seemingly logical and orderly division of the living world was destroyed by two discoveries in the 1880's. Winogradsky (1887, 1888, 1904) discovered chemosynthetic bacteria, i.e., cells without chlorophyll that could form their cellular substance by assimilating CO_2 in the dark; and Engelmann (1883, 1888) discovered the purple bacteria that carried on a kind of photosynthesis which apparently liberated no oxygen. Neither discovery was fully appreciated in its day; their effect was not that of an explosive charge, but rather that of a time bomb that did its devastation later.

The notion that nonphotosynthetic cells could form cellular substance by assimilating CO_2 was alien to the biology of the 19th century. It required intellectual daring to entertain even a milder proposition, namely, that animal tissues could transform non-carbohydrate foods into sugar. Louis Pasteur (1866) has eloquently described how Claude Bernard's earlier discovery of the glycogenic function of the liver has shaken the then unchallenged view that "only the vegetable kingdom was capable of forming a substance having the properties of sugars."

It is not surprising, therefore, that the far reaching consequences of Winogradsky's discovery were ignored by most of his contemporaries. One of the few exceptions was Lebedev, (1921) who characterized the conventional view of photosynthesis a "methodological error". Lebedev pointed out, with remarkable insight, that since the discovery of chemosynthetic bacteria revealed that CO_2 assimilation can also occur in the dark, it was no longer permissible to consider CO_2 assimilation as peculiar to photosynthetic cells. What was peculiar to these cells was their ability to use light as a source of energy for that process, whereas chemosynthetic organisms obtained the needed energy by oxidation of chemical substrates. CO_2 assimilation itself was, in both cases, an endergonic process, independent of light.

But Lebedev's views were too advanced to gain wide acceptance. This was delayed for over forty years. Only after the discovery of the Wood-Werkman reaction and the use of tracer isotopes by many investigators in the past twenty years, did it become generally recognized that all living cells, photosynthetic and non-photosynthetic, autotrophic and heterotrophic, assimilate CO_2 but differ as to the sources of energy that must be expended during this process.

The full impact of the discovery of photosynthetic bacteria was also delayed for about forty years. There was at first no compelling evidence for, and a great resistance to, the notion that photosynthesis could proceed without oxygen evolution. The view that CO_2 assimilation always involved a liberation of oxygen was so firmly entrenched that it was even extended to the dark CO_2 assimilation by chemosynthetic bacteria. For example, Lebedev's (1907, 1909) early conclusion about the fundamental similarity of CO_2 assimilation in chemosynthetic and photosynthetic organisms, rested on his belief that hydrogen bacteria use molecular oxygen, released by the decomposition of CO_2, for the oxidation of hydrogen gas. The idea, therefore, of photosynthesis without oxygen evolution seemed a contradiction of terms until the basic facts of bacterial photosynthesis were experimentally unravelled and clearly interpreted by the incisive work of van Niel (1931, 1949). It became evident that bacterial photosynthesis proceeds anaerobically without oxygen evolution and the hypothesis that light functioned in photosynthesis by decomposing CO_2 into "C" and O_2 could no longer be maintained.[2]

5. **CO_2 Assimilation as a Chemosynthetic Process.** If the function of light was not the photodecomposition of CO_2, where was the common role for light to be found in bacterial and plant photosynthesis? This ques-

[2] This generalization would apply only to the overall process of photosynthesis and would not exclude a *catalytic* participation of CO_2 in the mechanism of oxygen evolution in green plants as has recently been proposed by Warburg, Krippahl, Gewitz and Völker (1959) and supported by Stern and Vennesland (1960).

tion was answered by van Niel's hypothesis (1949) that envisaged a basic similarity between bacterial and plant photosynthesis in a common photochemical origin of the reductant for CO_2 assimilation. Van Niel proposed that the light reaction in both groups of organisms is a photolysis of water which results in the formation of a reductant (H) and an oxidant (OH), the latter being the precursor of molecular oxygen.

To account for the lack of oxygen evolution in bacterial photosynthesis, van Niel pointed to the requirement of this process for an external hydrogen donor. The external hydrogen donor was, in his postulation, required for reducing the (OH) back to water, and in this manner keeping the photosynthetic apparatus in bacteria active. Only in green plants did (OH) give rise to molecular oxygen and in this capacity for oxygen evolution lay the difference between bacterial and plant photosynthesis.

The postulated photolysis of water by radiation at an energy level of visible light, was a reaction unknown in chemistry. There were, therefore, no experimental restrictions on the surmises as to the nature of the CO_2 reductant, (H). One postulation which has figured in numerous hypotheses [see for example (Strehler 1953, Gaffron 1954)], considered (H) to be a "reducing power" of a potential sufficiently strong to reduce CO_2 to the level of carbohydrates by some mechanism that is peculiar to photosynthesis and different from the known biochemical reactions for the dark assimilation of CO_2. This hypothesis has thus far remained speculative.

The alternative view regarded CO_2 reduction as being a reversal of the well-known oxidative reaction of glycolysis, i.e., a dark reaction which, in photosynthesis, depends on only two products formed by light reactions, reduced pyridine nucleotide and ATP.[3] This hypothesis was formulated on theoretical grounds in 1943 by Ruben and incorporated earlier suggestions made by Thimann (1938) about CO_2 fixation and by Lipmann about a possible role of ATP in photosynthesis—the latter being the first, as far as I know, suggestion of this kind ever made (Lipmann 1941, p. 148).

Ruben's proposal distinguished two phases of sugar synthesis in the dark: a carboxylative phase, dependent on ATP only, in which CO_2 enters cellular metabolism by carboxylating an acceptor molecule, and a reductive phase, in which a carboxyl group is reduced by pyridine nucleotide with the aid of ATP.

In the ensuing fifteen years Ruben's scheme received experimental support mainly from the work of Calvin and his associates (Calvin 1956), who identified phosphoglyceric acid and other well-known products of glycolysis among the early products of photosynthesis.

A special feature of CO_2 assimilation in photosynthesis was found to

[3] The following abbreviations are used: ATP, adenosine triphosphate; ADP, adenosine diphosphate; P, orthophosphate; TPN, $TPNH_2$, oxidized and reduced forms of triphosphopyridine nucleotide; FMN, riboflavin phosphate (flavin mononucleotide).

be the carboxylation reaction that accounted for the appearance of phosphoglyceric acid as the first stable product of CO_2 fixation. Work in the laboratories of Calvin (1956), Horecker [Weissbach, Horecker and Hurwitz (1956)], Ochoa [Jakoby, Brummond and Ochoa (1956)], and Racker (1957) established the presence in photosynthetic tissues of two special enzymes, carboxydismutase and phosphoribulokinase, which accounted for the entry of CO_2 into the metabolism of photosynthetic cells by way of a five-carbon phosphorylated sugar, ribulose diphosphate. Ribulose diphosphate on combining with CO_2 is split to give two molecules of phosphoglyceric acid (cf. Calvin 1956, Vishniac, Horecker and Ochoa 1957).

However, even this special feature of carbon assimilation was soon found in non-photosynthetic bacteria as well. In fact, Trudinger (1956) and Aubert, Milhaud and Millet (1957) found the entire "photosynthetic carbon cycle" in the non-photosynthetic sulfur bacterium *Thiobacillus denitrificans*. It thus became clear that CO_2 assimilation is fundamentally extraneous to the photosynthetic process. All the reactions of CO_2 assimilation in photosynthesis occur also in non-chlorophyllous cells.

6. **Photosynthesis as an Energy Conversion Process.** The removal of CO_2 assimilation as the unique problem of photosynthesis has focused attention on what was already recognized a century ago as the key event in photosynthesis, on which all life on our planet depends: the conversion of light into chemical energy. This was first expressed with great clarity by two founders of thermodynamics, J. R. Mayer (1845), and Ludwig Boltzmann (1886). Mayer, who three years earlier enunciated the Law of Conservation of Energy, now stressed its applicability to plant life: "Plants are able only to convert energy not to create it" (p. 54). They accomplish this because, during their lifetime, they "absorb sunlight and use its force to add continuously to a sum of chemical difference" (p. 54).

Boltzmann, whose name is linked with the Second Law of Thermodynamics, expressed the cosmic significance of the photosynthetic energy conversion process in these words: "There exists between the sun and the earth a colossal difference in temperature; . . . the equalization of temperature between these two bodies, a process which must occur because it is based on the law of probability, will, because of the enormous distance and magnitude involved, last millions of years. The energy of the sun, may, before reaching the temperature of the earth, assume improbable transition forms. It thus becomes possible to utilize the temperature drop between the sun and the earth for performing work, as is the case with the temperature drop between steam and water."

"The universal struggle for existence in the living world is therefore not a struggle for raw materials—all organisms can find these in abundance in air, water and soil— . . . but a struggle for entropy that becomes available in the energy transition from the hot sun to the cold earth. To make

the most use of this transition, green plants spread the enormous surface of their leaves and, in a still unknown way, force the energy of the sun to carry out chemical syntheses, before it cools down to the temperature level of the earth's surface. These chemical syntheses are to us in our laboratories complete mysteries. The products of this chemical kitchen form the prize for which the animal world struggles" (Boltzmann 1886).

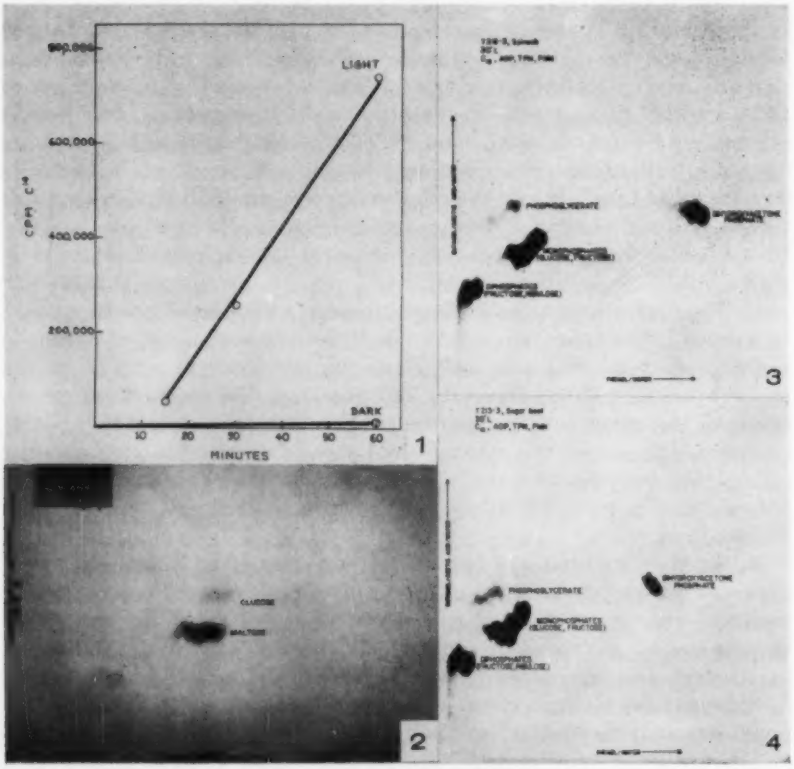
To investigators of photosynthesis the core of the energy conversion problem is the identification, by experiment rather than by surmise, of these "improbable energy transition forms" before they become consumed in the "chemical kitchen". Investigations of photosynthesis at the cellular level, in which the main preoccupation has usually been with CO_2 assimilation and oxygen evolution, led to no cogent theory of this primary act of photosynthesis that would explain the energy conversion process. As summed up recently by Livingston (1960) "physiologists and biochemists appear to believe that this question (the primary act of photosynthesis) was answered long ago by physicists while physicists find the problem distressingly complicated and therefore uninteresting." We will now examine what has been learned about this subject in the last six years from work on photosynthesis in cell-free systems.

7. **Photosynthesis as an Isolated Process.** In the intact cell the energy conversion in photosynthesis occurs simultaneously with non-photosynthetic energy conversion processes, notably respiration, that are essential to the maintenance of cellular structure and function. The products of photosynthesis become the substrates of respiration and, conversely, the products of respiration become the substrates of photosynthesis. This intertwining of the two processes extends to their intermediate products and to the enzymes and coenzymes that are concerned in the relevant syntheses and degradations.

Given the structural and functional complexity of an intact cell, it was apparent that the study of the energy conversion process of photosynthesis would be greatly simplified if it could be separated from the degradative energy conversion process of respiration. The most hopeful possibility for isolating photosynthesis from other physiological processes seemed to lie in chloroplasts. Isolated chloroplasts, freed from other cytoplasmic impurities do not respire—a conclusion (Arnon 1955, 1956a, b) which has recently received support from the work of James and Das (1957) and Warburg et al. (1959). If isolated chloroplasts were capable of carrying out complete photosynthesis then the process could be investigated independently of respiration.

Chloroplasts were once widely believed to be the site of complete photosynthesis, but this view was not supported by critical experimental evidence (Sachs 1887, Pfeffer 1900) and was later abandoned because of evidence that chloroplasts when removed from cells cannot assimilate CO_2 (Hill 1951, Brown and Franck 1948).

In 1953, Rabinowitch wrote that "the task of separating it (photosynthesis) from other life processes in the cell and analyzing it into its essential chemical reactions has proved to be more difficult than was anticipated. The photosynthetic process, like certain other groups of reactions in living cells, seems to be bound to the structure of the cell; it cannot be repeated outside that structure." In 1954, Lumry, Spikes and Eyring summed up the many investigations with isolated chloroplasts as pointing to the conclusion that the chloroplast was a "system much simpler than that required



Figs. 1–4.—Fig. 1. Time course of CO_2 fixation by isolated spinach chloroplasts in light and dark. The reaction mixture is described by Allen, Arnon, Capindale, Whatley and Durham 1955.—Fig. 2. Identification of starch as the insoluble product of photosynthesis by isolated choloroplasts. Radioautograph of a chromatogram showing products of hydrolysis by salivary amylase of the insoluble compounds formed during illumination. Further details are given by Allen, Arnon, Capindale, Whatley and Durham 1955. —Fig. 3. Products of CO_2 assimilation by illuminated choloroplasts isolated from spinach.—Fig. 4. Products of CO_2 assimilation by illuminated choloroplasts isolated from sugar beet.

for photosynthesis'' and was the site of only ''the light-absorbing and water-splitting reactions of the overall photosynthetic process'' (Hill reaction).

The possibility has always remained that the observed failure of isolated chloroplasts to fix CO_2 was merely a consequence of inappropriate experimental methods that were used in different laboratories, including our own (Arnon 1951). Further work with isolated chloroplasts has shown that the difficulties were indeed methodological. In 1954, another phase of chloroplast investigations began with the discovery that, with improved isolation techniques, whole chloroplasts can assimilate carbon dioxide (Arnon, Allen and Whatley 1954). Photosynthesis, as it is usually defined (Rabinowitch 1945, p. 61), was found to be independent of the organization of the living cell. Reduction of carbon dioxide to carbohydrates, accompanied by oxidation of water to oxygen, was carried out, at physiological temperatures and with no energy supply except visible light, by isolated chloroplasts unaided by other cellular particles or enzyme systems (Arnon 1955, Allen, Arnon, Capindale, Whatley and Durham 1955).

CO_2 fixation by isolated chloroplasts was strictly light-dependent and proceeded at an almost constant rate for at least an hour (fig. 1). There was approximate correspondence (table 1) between the oxygen evolved and the

TABLE 1. *CO_2 fixation and oxygen production by isolated chloroplasts.*

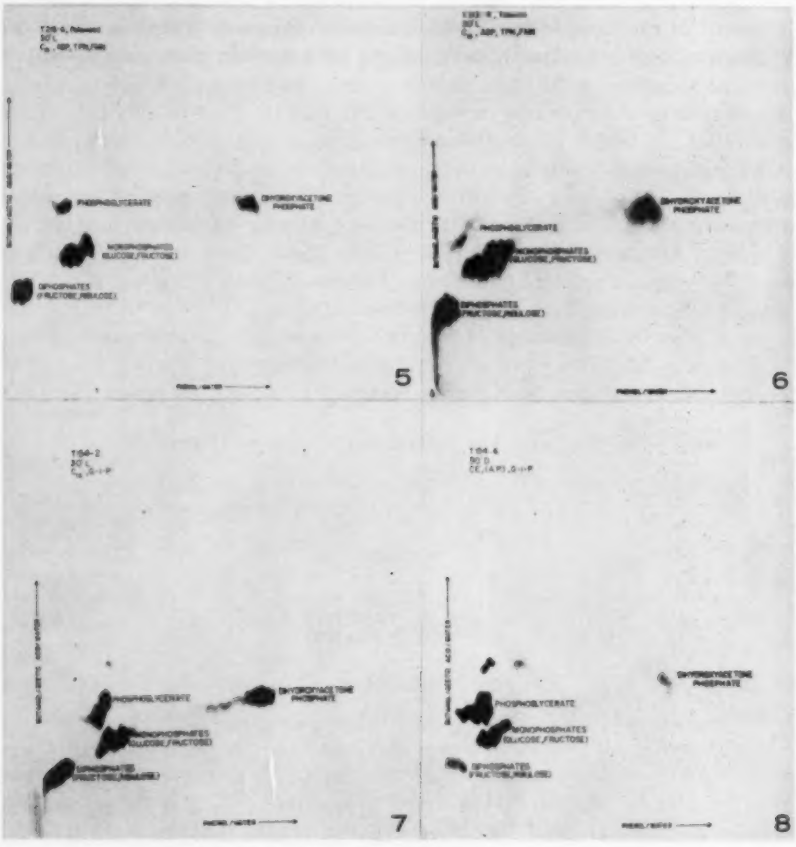
Expt.	$C^{14}O_2$ fixed, μM.	O_2 produced, μM.
A	1.0	1.5
B	0.81	0.83
C	0.38	0.50
D	1.04	1.0

CO_2 fixed, as would be expected from the well known photosynthetic quotient in green plants, $\frac{O_2}{CO_2} = 1$. The products of CO_2 assimilation were found to be the same as in photosynthesis by whole cells. The insoluble product of CO_2 fixation by chloroplasts was identified as starch (fig. 2). Among the soluble products the following were found: Phosphate esters of fructose, glucose, ribulose, sedoheptulose, dihydroxyacetone, and glyceric acid; glycolic, malic, aspartic acids, alanine, glycine and free dihydroxyacetone and glucose. Using similar techniques, investigators in several different laboratories have confirmed the ability of illuminated chloroplasts to form in light, starch and sugars from CO_2 and water (literature cited by Arnon 1961a).

Most of the early work on extracellular photosynthesis was done with spinach chloroplasts. But more recently, the same products of CO_2 assimilation in light were also obtained with isolated chloroplasts from several

different species: sugar beet, sunflower, *Phytolacca americana* and *Tetragonia expansa* (Whatley, Allen, Trebst and Arnon 1960). The soluble products of CO_2 assimilation by isolated chloroplasts from spinach, sugar beet, tobacco and *Phytolacca americana* are shown in figs. 3, 4, 5, and 6.

There was thus, finally, a firm experimental basis for concluding that



Figs. 5–8.—Fig. 5. Products of CO_2 assimilation by illuminated chloroplasts isolated from pokeweed, *Phytolacca americana*.—Fig. 6. Products of CO_2 assimilation by illuminated chloroplasts isolated from tobacco.—Fig. 7. Radioautograph of a chromatogram showing products of photosynthetic $C^{14}O_2$ assimilation by illuminated chloroplasts. —Fig. 8. Radioautograph of a chromatogram showing products of *dark* $C^{14}O_2$ assimilation by a chlorophyll-free extract of chloroplasts that has been supplemented with ATP and $TPNH_2$, formed in a previous light reaction. The extract was made of the same chloroplasts that were used in fig. 7.

chloroplasts are indeed the sites of complete photosynthesis in green plants. In the light of the new evidence, chloroplasts emerged as remarkably complete and autonomous cellular structures that have become specialized for carrying out the complete process of photosynthesis in green plants. It seemed legitimate therefore to explore the component photochemical reactions in isolated chloroplasts with the expectation that they would also be relevant to photosynthetic events in intact cells.

8. **The Role of Light in CO_2 Assimilation.** Before the equivalence of photosynthesis in isolated chloroplasts and whole cells could be accepted with confidence, it was necessary to determine whether the process of CO_2 assimilation by isolated chloroplasts followed the same pathway as in algal cells and leaves. This was done by subdividing the chloroplasts into component parts and identifying in them, or isolating from them, the individual enzyme systems that account for the conversion of CO_2 to carbohydrate (Losada, Trebst and Arnon 1960, Trebst, Losada and Arnon 1960). The

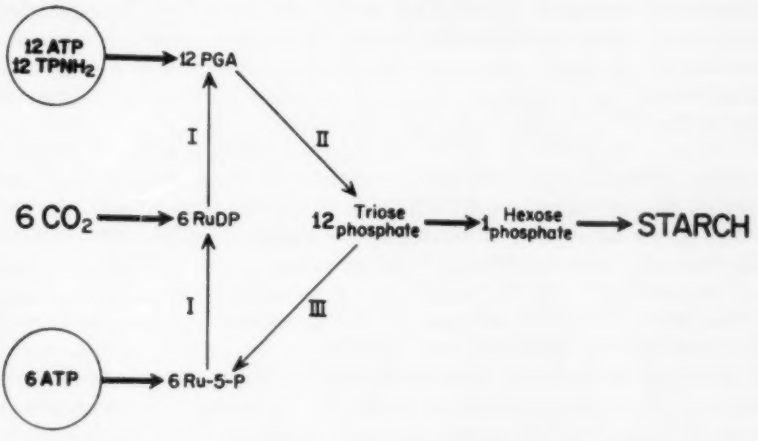


Fig. 9. Condensed diagram of the reductive carbohydrate cycle in chloroplasts. The cycle consists of three phases. In the carboxylative phase (I), ribulose-5-phosphate (Ru-5-P) is phosphorylated to ribulose diphosphate (RuDP) which then accepts a molecule of CO_2 and is cleaved to 2 molecules of phosphoglyceric acid (PGA); in the reductive phase (II) PGA is reduced to triose phosphate; in the regenerative phase (III) triose phosphate is partly converted into Ru-5-P and partly into hexose phosphate and starch. All the reactions of the cycle occur in the dark. The reactions of the carboxylative and reductive phases are driven by ATP and $TPNH_2$ formed in the light. One complete turn of the cycle results in the assimilation of 1 mole of CO_2 at the expense of 3 moles of ATP and 2 moles of $TPNH_2$.

results have established that in isolated chloroplasts, as in whole cells, the conversion of CO_2 to carbohydrate proceeds by the same series of dark reactions that are driven by ATP and $TPNH_2$ ($TPNH_2$, not $DPNH_2$, was the reduced pyridine nucleotide formed by illuminated chloroplasts). The general scheme for CO_2 assimilation by isolated chloroplasts is summarized in fig. 9.

The validity of the scheme shown in fig. 9 was supported by a physical separation of the light and dark reactions of photosynthesis in chloroplasts (Trebst, Tsujimoto and Arnon 1958). The light phase was carried out first by the complete chloroplast system in the absence of CO_2 and resulted in an evolution of oxygen accompanied by an accumulation of $TPNH_2$ and ATP in the reaction mixture. The green portion of the chloroplasts ("grana") was then discarded and when CO_2 was next supplied to the remaining non-green portion of the chloroplasts in the *dark*, it was converted to sugar phosphates. As shown in figs. 7 and 8, the light and dark phases, when carried out separately, yielded essentially the same final photosynthetic products as the continuously illuminated chloroplast system. The products included hexose and pentose mono- and diphosphates, phosphoglyceric acid, dihydroxyacetone phosphate, and small amounts of phosphoenolpyruvate and malate (Trebst, Tsujimoto and Arnon 1958).

The same products of CO_2 assimilation by chlorophyll-free chloroplast extracts, including phosphorylated sugars, were also obtained in a total dark chemosynthesis where $TPNH_2$ and ATP were not supplied by a preceding photochemical reaction but were prepared either chemically or enzymatically, or were derived from animal material (Trebst, Tsujimoto and Arnon 1958). [Similar experiments were carried out earlier by Racker (1955, 1958) with a multi-enzyme system that included enzymes from rabbit muscle, yeast, and spinach leaves].

The experiments with isolated chloroplasts have thus underlined the essence of photosynthesis in green plants, i.e., the energy conversion process, as comprising those chloroplast reactions in which $TPNH_2$ and ATP are formed by light. The carboxylation reaction resulting in the formation of phosphoglyceric acid (PGA) requires ATP, and the reduction of PGA to the level of carbohydrate requires both ATP and reduced pyridine nucleotide. The distinction between photosynthetic and non-photosynthetic cells seems to lie, therefore, in the manner in which ATP and reduced pyridine nucleotide are formed. Photosynthetic cells form these compounds at the expense of light energy, whereas non-photosynthetic cells form them at the expense of energy released by dark reactions.

9. **Photosynthetic Phosphorylation.** With respect to $TPNH_2$ it has already been shown by several laboratories that isolated chloroplasts were capable of reducing TPN to $TPNH_2$ in light, with a simultaneous evolution of oxygen (Vishniac and Ochoa 1951; Tolmach 1951; Arnon 1951). What

remained to be determined was the source of ATP in photosynthesis, or, more specifically, the cellular site and the mechanism by which ATP is being formed during photosynthesis. From the standpoint of cellular physiology, the important question is whether the ATP used in photosynthesis is supplied by some light-driven assimilation of inorganic phosphate that is peculiar to photosynthesis, or whether the ATP used in photosynthesis is supplied by respiration.

Before the recent investigations with isolated chloroplasts the only cytoplasmic particles known to form ATP were mitochondria, by the process of oxidative phosphorylation (Lehninger 1955). Oxidative phosphorylation by mitochondria has therefore usually been invoked in explaining the source of ATP used in photosynthesis (see, for example, fig. 7 in Bassham et al. 1954, also review by Arnon 1956a). In early models of ATP formation in photosynthesis it was proposed that the reduction of pyridine nucleotide was carried out by illuminated chloroplasts and the resulting reduced pyridine nucleotide was reoxidized with molecular oxygen by mitochondria (Vishniac and Ochoa 1952). This coupled chloroplast-mitochondrial system differed from conventional oxidative phosphorylation only in the source of the reduced pyridine nucleotide. In one case the pyridine nucleotide was reduced by light and in the other by a respiratory substrate. The phosphorylation reactions proper leading to the synthesis of ATP were in both cases dependent on enzymes localized in mitochondria.

This model for the generation of ATP in photosynthesis posed a serious difficulty. The most specialized photosynthetic tissue, the mesophyll of leaves, is noted for its paucity of mitochondria. Within the mesophyll cells, especially in the palisade parenchyma, chloroplasts are the dominant cytoplasmic bodies; mitochondria are few (Esau 1953, James and Das 1957). It was difficult, therefore, to visualize how oxidative phosphorylation by mitochondria could generate enough ATP in leaf tissues that are noted for their vigorous photosynthetic activity.

The difficulty was removed in 1954, when isolated chloroplasts were found to synthesize ATP in light without the aid of mitochondria (Arnon, Allen and Whatley 1954). When conditions were so arranged that CO_2 assimilation was excluded, isolated chloroplasts used light energy for the esterification of inorganic phosphate in accord with the overall reaction:

$$1. \qquad n \cdot P + n \cdot ADP \xrightarrow{\text{light}} n \cdot ATP$$

Light-induced ATP formation in chloroplasts raised at once the question whether this process is analogous to oxidative phosphorylation by mitochondria. At least two fundamental differences were apparent. ATP formation by illuminated chloroplasts occurred without the consumption of molecular oxygen and without the addition of a chemical substrate to supply

free energy needed for the formation of the pyrophosphate bonds of ATP. The term *photosynthetic phosphorylation* (Arnon, Allen and Whatley 1954; Arnon 1955) was, therefore, given to the light-induced ATP formation by chloroplasts to distinguish it from oxidative (respiratory) phosphorylation by mitochondria and the anaerobic phosphorylations at substrate level that occur in glycolysis. In both of these processes ATP formation occurs at the expense of energy liberated by the oxidation of a chemical substrate, whereas the only "substrate" which is being consumed in photosynthetic phosphorylation is light.

10. **Photosynthetic Phosphorylation in Chloroplasts and Bacteria.** Although there was no net consumption of molecular oxygen in photosynthetic phosphorylation (as measured by manometric pressure change), the process, when first discovered, proceeded at a sustained rate only in the presence of oxygen (Arnon, Allen and Whatley 1954, fig. 2b). Oxygen thus acted as a catalyst in photosynthetic phosphorylation, not as a substrate, as it does in oxidative phosphorylation. A decisive difference between photosynthetic and oxidative phosphorylation was the inability of form chloroplasts to form ATP in the dark by oxidizing hydrogen donors of oxidative phosphorylation with molecular oxygen (Arnon, Allen and Whatley 1956).

Further investigation of photosynthetic phosphorylation by spinach chloroplasts soon resulted in the identification of FMN and vitamin K as catalysts in the process (Arnon, Whatley and Allen 1954, p. 6326; Whatley, Allen and Arnon 1955; Arnon, Whatley and Allen 1955). At optimal (but still catalytic) concentrations of either FMN or vitamin K, photosynthetic phosphorylation became independent of external oxygen and proceeded vigorously in an atmosphere of nitrogen or argon. Without added FMN or vitamin K (Arnon, Allen and Whatley 1954) or on adding low, "microcatalytic" concentrations of these cofactors, photosynthetic phosphorylation remained dependent on oxygen, although still showing no net oxygen consumption (Arnon, Whatley and Allen 1954, unpublished data).

These findings are in agreement with the results of Wessels (1958), Jagendorf and Avron (1959) and Nakamoto, Krogmann and Vennesland (1959), that photosynthetic phosphorylation with suboptimal amounts of cofactors is oxygen-dependent but becomes oxygen-independent at higher concentrations of cofactors.

In charting their subsequent investigations, Arnon and his associates laid special stress on the anaerobic photosynthetic phosphorylation which proceeds in isolated chloroplasts at optimal catalytic concentrations of FMN and vitamin K. They considered this type more fundamental to photosynthesis in general than the oxygen-catalyzed type because it would also apply to bacterial photosynthesis, in which oxygen cannot be involved.

Soon after the discovery of photosynthetic phosphorylation in isolated chloroplasts, Frenkel (1954) reported a similar phenomenon in the photo-

synthetic bacterium *Rhodospirillum rubrum*. Although Frenkel suggested that the light-induced ATP formation in bacterial preparations was similar to that found in chloroplasts by Arnon, Allen and Whatley (1954), the similarity seemed uncertain at first, because Frenkel's photophosphorylation system, which was a sonic macerate of *R. rubrum* cells, differed in several respects from its counterpart in isolated chloroplasts. Frenkel's preparations became substrate-dependent after washing; the rate of phosphorylation was doubled on adding α-ketoglutarate (Frenkel 1954). But in later experiments he ruled out the dependence on an added chemical substrate (Frenkel 1956) and the equivalence of chloroplast and bacterial photophosphorylation seemed probable.

Frenkel's findings were followed by those of Williams (1956) who demonstrated photosynthetic phosphorylation in cell-free preparations of the obligately anaerobic photosynthetic bacteria, *Chromatium* and *Chlorobium*. It thus became clear that a common *anaerobic* mechanism for a light-induced phosphorylation, that does not depend on an exogenous chemical substrate or on oxygen consumption, is shared by both green plants and photosynthetic bacteria. The energy conversion process proper seemed to be fundamentally independent of oxygen although it was still possible that details of mechanisms were different in green plants and photosynthetic bacteria.

The discovery of photosynthetic phosphorylation in chloroplasts by Arnon, Allen and Whatley (1954) and in bacterial particles by Frenkel (1954) was confirmed and extended in a number of laboratories. Photosynthetic phosphorylation in isolated chloroplasts was observed by Avron and Jagendorf (1957), Wessels (1957), and Chow and Vennesland (1957); in algae by Thomas and Haans (1955) and Petrack (1959); and in photosynthetic bacteria by Williams (1956), Geller (1957), Kamen and Newton (1957) and Anderson and Fuller (1958). In later experiments Whatley, Allen, Trebst and Arnon (1960) have shown that, like CO_2 assimilation, photosynthetic phosphorylation by chloroplasts, which had previously been almost entirely limited to observations on chloroplasts isolated from one species, viz., spinach, is also operating in chloroplasts isolated from several other species of higher plants. It now seems well established, therefore, that all photosynthetic organisms contain a phosphorylating system that is intimately associated with, and structurally bound to, the chlorophyll pigments.[4]

Soon after the demonstration of photosynthetic phosphorylation in

[4] Other accounts of the discovery of CO_2 assimilation and photosynthetic phosphorylation by isolated chloroplasts are sometimes found in the literature. Bassham and Calvin (1956, p. 31) ascribed the discovery of CO_2 assimilation by isolated chloroplasts to Boychenko and Baranov (1954). Later, Calvin (1959a, p. 152) ascribed the discovery of both CO_2 assimilation and ATP synthesis by isolated chloroplasts to his own laboratory.

isolated chloroplasts, attempts were made to compare its rate with that of CO_2 assimilation by illuminated whole cells. Since as with most newly isolated processes in cell-free systems,[5] the rates of photosynthetic phosphorylation were rather low, there was little inclination at first to accord this process quantitative importance (cf. Gaffron 1957, pp. 292, 345) as a mechanism for converting light into chemical energy.

With further improvement in experimental methods we obtained rates of photosynthetic phosphorylation up to 170 times higher (Allen, Whatley and Arnon, 1958) than those originally described (Arnon, Allen and Whatley, 1954) and even these high rates were exceeded by Jagendorf and Avron (1958). The improved rates of photosynthetic phosphorylation were equal to or greater than the maximum known rates of carbon assimilation in intact leaves. It appeared, therefore, that the enzymatic apparatus for photosynthetic phosphorylation that is present in chloroplasts can, under appropriate experimental conditions, function outside the organized cell without substantial loss of activity.

Unlike the phosphorylating system, the enzymes catalyzing CO_2 assimilation are water-soluble (Arnon, Allen, Whatley, Capindale and Rosenberg, 1955, Whatley et al., 1956) and are, therefore, partly lost during the isolation of chloroplasts. This results in lower rates of CO_2 assimilation by isolated chloroplasts than by the intact parent leaves. The difference between the rate of CO_2 assimilation by isolated chloroplasts and that of intact leaves may be made to appear greater, though less relevant, if the comparison is made not between isolated chloroplasts and their parent leaf tissue, but between isolated chloroplasts and unrelated leaf material that gave maximum rates of CO_2 assimilation under different experimental conditions. Nevertheless, the rates of CO_2 assimilation in isolated chloroplasts [10 to 20 per cent of that in parent leaf tissue (Losada, Trebst and Arnon, 1960, Smillie and Fuller, 1959)] are substantial enough to strengthen the conclusion that photosynthesis by isolated chloroplasts mirrors that in the intact leaf. This conclusion is fortified by the identity of the photosynthetic products found in both cases.

11. **The Electron Flow Mechanism of Photosynthetic Phosphorylation.** Anaerobic photosynthetic phosphorylation has provided direct experimental evidence for the view that the conversion of light into a form of chemical energy, (ATP) is independent of the classical manifestations of photosynthesis in green plants: CO_2 assimilation and oxygen evolution. The sole product of the anaerobic photosynthetic phosphorylation is ATP and the salient fact which must be explained is that a "high-energy"

[5] The most recent instance of this kind, the cell-free synthesis of DNA, is thus described by Kornberg (1960): "The first positive results represented the conversion of only a very small fraction of the acid-soluble substrate into an acid-insoluble fraction (50 or so counts out of a million added)."

pyrophosphate bond is formed at the expense of absorbed light energy. There is no need, *a priori*, to connect this reaction either with photolysis of water or with reduction of CO_2.

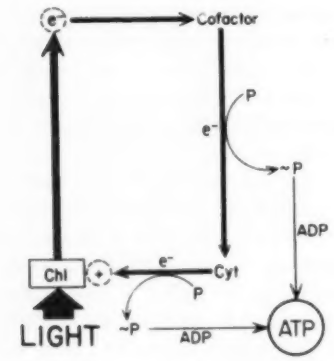
The simplest hypothesis to account for the formation of ATP in photosynthetic phosphorylation is to assume that, as in the dark phosphorylations of glycolysis and respiration, the formation of a pyrophosphate bond is also coupled with a release of free energy which occurs during electron transport, i.e., when an electron drops from the higher energy level that it has when it resides in the electron donor molecule to the lower energy level that it assums on joining the electron acceptor molecule. But a mechanism for photosynthetic phosphorylation must also account for its unique features: ATP is formed without the consumption of an exogenous electron donor and electron acceptor. Unlike oxidative phosphorylation, photosynthetic phosphorylation consumes neither exogenous substrate nor molecular oxygen, only light energy.

A mechanism for photosynthetic phosphorylation must, therefore, provide for the generation of both an electron donor and an electron acceptor in the primary photochemical act when radiant energy is absorbed by chlorophyll. The mechanism of photosynthetic phosphorylation that we have proposed (Arnon, 1959, 1960, 1961a, b) regards the *photosynthetic particle*, chloroplast or bacterial chromatophore, as a "closed" catalytic system. We have suggested that during the primary photochemical act, one component of the "closed" system, chlorophyll (bound to protein), becomes excited on absorbing a photon and "expels" one of its electrons that has been raised to a higher energy level (Lewis and Lipkin, 1942). The excited chlorophyll thus becomes the electron donor. On losing an electron, chlorophyll assumes an oxidized state[6], and in this way also becomes the electron acceptor in photosynthetic phosphorylation.

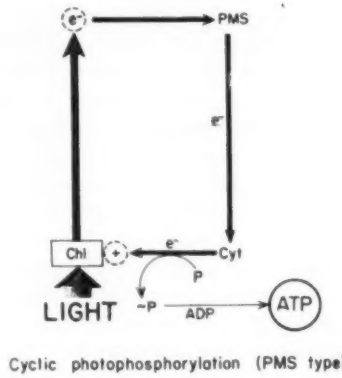
The "expelled" electron returns in a stepwise manner, via several electron carriers, to the oxidized chlorophyll molecule which thereupon resumes its normal ground state. On its return "downhill" path, the expelled electron releases free energy as it passes through the several electron carriers. The electron carriers are vitamin K, FMN (or related physiological equivalents) and cytochromes. These intermediate electron carriers are coupled with enzyme systems that catalyze the phosphorylation process during which electron energy is converted into pyrophosphate bond energy. A diagram illustrating this concept is shown in fig. 10. Evidence in its support is discussed elsewhere (Arnon 1959, 1961 a, b).

Certain non-physiological agents, such as phenazine methosulfate, have been found to catalyze photosynthetic phosphorylation in bacterial chromatophores (Geller 1957, Kamen and Newton 1957) and in chloroplasts

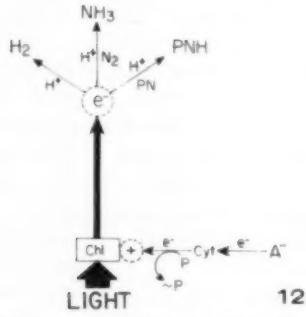
[6] For a review of oxidation-reduction reactions of *solutions of pure chlorophyll* in various solvents see Rabinowitch (1945, 1956).



Anaerobic cyclic photophosphorylation 10

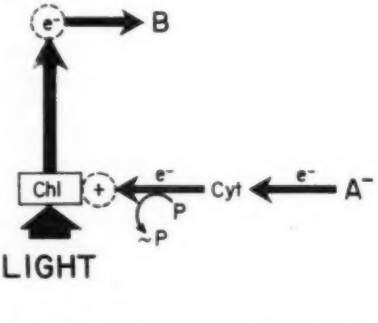


Cyclic photophosphorylation (PMS type) 11



12

Non-cyclic electron transport in Chromatium



13

Non-cyclic photophosphorylation of bacterial type

Figs. 10–13.—Fig. 10. Scheme for anaerobic cyclic photophosphorylation catalyzed by vitamin K_3 or FMN. Details in the text.—Fig. 11. Scheme for anaerobic cyclic photophosphorylation catalyzed by phenazine methosulfate (PMS). Details in the text.—Fig. 12. Scheme for noncyclic electron flow in *Chromatium*. Details in the text.—Fig. 13. Scheme for noncyclic photophosphorylation of the bacterial type. Details in the text.

(Jagendorf and Avron 1958) and presumably act by providing artificial "shortcuts" for the physiological electron pathway (Geller 1957). (Compare fig. 11 with fig. 10).

The stepwise interaction of the "activated" electron with the intermediate electron acceptors and the phosphorylating system constitutes the energy conversion process in photosynthetic phosphorylation. Because of the cyclic path travelled by electrons that are activated by light, this type of photosynthetic phosphorylation has been called *cyclic photophosphorylation* (Arnon, Whatley and Allen 1958, Arnon 1959).

Chlorophyll can, of course, also be restored to the ground state without

the excited electron going through the enzymatic "energy transformer stations," but in that case electron energy has not been converted into chemical energy and hence photosynthesis has not occurred. Instead, the energy of electronic excitation is emitted as a light quantum and the characteristic fluorescence of chlorophyll is observed.

To summarize, then, the simplest case of conversion of light energy into chemical energy, a case that is common to all chlorophyll-containing particles, is cyclic photophosphorylation. In cyclic photophosphorylation electrons flow from chlorophyll to a cofactor (figs. 10 and 11), from the cofactor to cytochromes and from cytochromes back to chlorophyll. During this cyclic flow of electrons the cytochromes present in the photosynthetic particles undergo oxidation-reductions which are coupled to phosphorylation reactions that produce ATP.

The proposed mechanism for this process may be divided into three phases: (a) the light-induced generation of a high-energy electron and the ultimate electron acceptor [chl*], (b) electron transport by a photosynthetic electron transport chain, and (c) phosphorylation reactions coupled to electron transport. Phases (b) and (c) are analogous and possibly identical in some respects with their counterparts in oxidative phosphorylation, whereas phase (a) is peculiar to photosynthetic phosphorylation.

12. **Cyclic Photophosphorylation as Primitive Photosynthesis.** The photophosphorylating system is structurally bound to chlorophyll in the smallest particles that function as units in the absorption of light energy, the chromatophores of bacteria and the grana of the chloroplasts. The close structural association of the phosphorylating activity with the chlorophyll pigments suggests that the harnessing of light energy in photosynthesis is more closely associated with ATP formation than with CO_2 assimilation. The enzymes responsible for CO_2 assimilation are easily dissociable from grana in the case of chloroplasts (Arnon 1956b), and not even structurally joined together in the case of bacterial chromatophores (Anderson and Fuller 1958; Losada, Trebst, Ogata and Arnon 1960). These facts are in agreement with the view that, in the course of biochemical evolution, photosynthesis first emerged as a process for converting light energy into ATP, and this "primitive" photosynthesis became only later a process linked to CO_2 reduction (Losada, Trebst, Ogata and Arnon 1960).

In the conventional view of photosynthesis, derived mainly from the study of this process in green plants, the chemical energy formed by the conversion of absorbed light is always used for the reduction of CO_2. The case of cyclic photophosphorylation being a "primitive" photosynthesis in the evolutionary sense, would therefore be strengthened if examples could be found today of cases in which the contribution of light to carbon assimilation could be experimentally limited to the formation of ATP.

Two such cases of photosynthesis in *Chromatium* have recently been described by Losada, Trebst, Ogata and Arnon (1960). In one case the sole source of carbon was acetate and in the other CO_2. The photoassimilation of acetate occurred in the absence of an external hydrogen donor whereas in the photoassimilation of CO_2 the reductant was exogenous hydrogen gas. The sole contribution of light in both cases was the formation of ATP.

The experimental substitution of ATP for light was considered particularly significant because it was found in such photosynthetic bacteria as *Chromatium,* that are unique in the living world in being strict phototrophs. *Chromatium,* unlike, for example, *Chlorella* or photosynthetic bacteria of the genus *Rhodospirillum,* cannot replace its light-dependent mode of life by a heterotrophic, aerobic metabolism in the dark (van Niel 1931, 1949, Müller, 1933). *Chromatium* grows only in the light (van Niel 1931, 1949), and being an obligate anaerobe, does not provide an alternative way for forming ATP by the mechanism of oxidative phosphorylation.

As regards the photoassimilation of acetate in another photosynthetic bacterium, the facultative anaerobe *R. rubrum*, a similar view that the contribution of light is limited to cyclic photophosphorylation was recently expressed, on the basis of independent evidence, by Stanier, Doudoroff, Kunisawa and Contopoulou (1959).

In certain circumstances, ATP formation may be the sole contribution of the photosynthetic process, not only in bacteria but also in higher plants. We have suggested elsewhere (Arnon, Whatley and Allen 1958) that in green plants cyclic photophosphorylation may continue forming ATP when CO_2 assimilation is, for one reason or another, reduced or even stopped altogether. This might arise during the well-known midday closure of stomata in leaves of higher plants (Stålfelt 1955, Heath and Orchard 1957) which restricts the supply of CO_2. The closure of stomata often coincides with an abundance of starch and an incipient water deficit in the photosynthesizing cells. Under these conditions cyclic photophosphorylation, which consumes neither CO_2 nor water, would be a useful device for generating ATP to drive the many ATP-dependent reactions, notably the synthesis of polysaccharides, proteins and fats.

These theoretical deductions for higher plants have received recently experimental support from the work of Maclachlan and Porter (1959). They reported the first known instance of utilization of light energy in leaf tissue for the synthesis of starch from labelled glucose, under conditions when CO_2 assimilation was excluded but cyclic photophosphorylation could proceed.

13. **Pyridine Nucleotide Reduction by Hydrogenase in the Dark.** In the examples of photosynthesis in which the contribution of light was

limited to ATP formation, no reductant was needed in the conversion of glucose to starch in leaves. In the case of acetate, its assimilation by *Chromatium* yields hydrogen for metabolic purposes and is thus independent of an exogenous hydrogen donor (Losada, Trebst, Ogata and Arnon 1960). But the assimilation of CO_2 requires, in addition to ATP, a supply of a reductant, i.e., reduced pyridine nucleotide. It was stated earlier that in photosynthesis of green plants both of these components of assimilatory power are formed at the expense of light energy. It is necessary, therefore, to trace the transition from a primitive photosynthesis in which light is used only for the formation of ATP to the "advanced" type of photosynthesis, observed in green plants, in which light energy is used not only for ATP formation but also for the reduction of pyridine nucleotide and the accompanying evolution of oxygen.

In the photoassimilation of CO_2 by *Chromatium* the added reductant was hydrogen gas (cf. Roelofsen 1934). This is the simplest reductant usable by living cells. Cell-free hydrogenases from nonphotosynthetic bacteria are known to reduce pyridine nucleotides with molecular hydrogen (Korkes 1955; Peck and Gest 1954), but no evidence for this dark reaction was found in photosynthetic bacteria (Karunairatnam and Gest 1958).

The subject was reinvestigated by Ogata, Nozaki and Arnon (1959), using the cell-free hydrogenase of *Chromatium*. The *Chromatium* hydrogenase, localized in the chromatophores, reduced DPN and TPN with molecular hydrogen in the dark in the presence of benzyl viologen. The enzyme was more active toward DPN than TPN.

These results indicated that in the presence of hydrogen gas, *Chromatium* cells do not require light for the reduction of pyridine nucleotides. The role of light is then limited to ATP formation, without which CO_2 assimilation cannot occur (Losada, Trebst, Ogata and Arnon 1960). Photosynthesis by *Chromatium* in the presence of molecular hydrogen may, therefore be summarized as follows:

LIGHT PHASE

Cyclic photophosphorylation : $n \cdot ADP + n \cdot P \longrightarrow n \cdot ATP$

DARK PHASE

DPN reduction : $2\ DPN + 2\ H_2 \longrightarrow 2\ DPNH_2$

CO_2 assimilation : $CO_2 + 2\ DPNH_2 + n \cdot ATP \longrightarrow (CH_2O) + H_2O + 2\ DPN + n \cdot ADP + n \cdot P$

SUM : $CO_2 + 2\ H_2 \xrightarrow{\text{light}} (CH_2O) + H_2O$

Several algal species are known to contain hydrogenases and to acquire, after adaptation to hydrogen, a capacity to photo-assimilate CO_2 with the

aid of molecular hydrogen (Gaffron 1939, 1944, Frenkel and Lewin 1954). This process, which Gaffron (1944) named *photoreduction*, appears to be the same type of photosynthesis as that in *Chromatium* when it is supplied with hydrogen gas. It seems likely that photoreduction by algae is a reversion to a primitive photosynthesis in which the CO_2 reductant was hydrogen gas present in the environment and the sole contribution of light was the formation of ATP by cyclic photophosphorylation.

14. **The Photoreductant in Bacteria.** Although photosynthetic bacteria when supplied with hydrogen gas do not require light energy for the production of $DPNH_2$ (or $TPNH_2$), a different situation arises when photosynthetic bacteria are grown with such hydrogen or electron donors as succinate or thiosulfate (van Niel 1931, Müller 1933). Electrons donated by these substances have an insufficient reducing potential for directly reducing DPN (or TPN) in the dark.

Additional energy is then required to bring about the reduction of DPN (or TPN) and, in a photosynthetic mode of life without oxygen which is characteristic of photosynthetic bacteria, this additional energy must come from light. If the electron flow mechanism is fundamental to the conversion of light into chemical energy, how can it apply to the photoreduction of pyridine nucleotides by thiosulfate or succinate?

An attractive hypothesis was to consider bacterial photosynthesis with thiosulfate and succinate as an extension of bacterial photosynthesis with hydrogen gas, when the photochemical events proper are restricted to the formation of ATP by cyclic photophosphorylation. The primary photochemical act that results in the generation by illuminated chlorophyll of a high-energy electron and of the ultimate electron acceptor, $[Chl^*]$, would be the same in both cases. But in the thiosulfate and succinate type of bacterial photosynthesis, not all of the high-energy electrons would return via the cylic route to $[Chl^*]$. Some of them would be passed on to pyridine nucleotide and used for CO_2 assimilation.

The electrons so removed from the photoreceptor particle would be replaced by electrons donated by thiosulfate or succinate. This electron transfer would be mediated by cytochromes. Thiosulfate and succinate would thus act as hydrogen donors that reduce bacterial cytochromes after these are oxidized by chlorophyll in light. The cytochrome system in photosynthetic bacteria would be a gateway for the entry of electrons and for their transfer to chlorophyll, where they would be raised to a higher reducing potential at the expense of the energy of absorbed light.

The proposed sequence of reactions in photosynthetic bacteria will be collectively designated as the noncyclic electron flow mechanism. The three components of the noncyclic electron flow mechanism are (a) an external electron donor system (represented here by thiosulfate or succinate) (b) the photosynthetic particle (chromatophore) which raises the donated electron

to a higher reducing potential at the expense of the energy of light and (c) the electron acceptor system (exemplified by DPN or TPN).

Experimental support for the non-cyclic electron flow mechanism in bacterial photosynthesis has recently become available. *Chromatium* particles were found to have enzymes catalyzing the transfer of electrons from thiosulfate and succinate to cytochromes (Losada, Nozaki and Arnon 1961; Arnon 1961a).

Illuminated photosynthetic bacteria reduce pyridine nucleotides in the presence of succinate or some other electron donor that is less reduced than pyridine nucleotides. The photoreduction of DPN was observed by Frenkel (1958) and Vernon and Ash (1959) in *R. rubrum*, and by Ogata, Nozaki and Arnon (1959) in *Chromatium*. In more recent experiments we have found that in the presence of succinate and light, unwashed chromatophores from *R. rubrum*, unaided by enzymes from chloroplasts, reduce both DPN and TPN.

Additional support for the noncyclic electron flow mechanism in bacterial photosynthesis has come from recent experiments on the photoproduction of hydrogen gas and photofixation of nitrogen gas. These two phenomena were known to occur in photosynthetic bacteria and in algae (cf., review, Gest and Kamen 1960). The new findings were that photoproduction of hydrogen gas and photofixation of nitrogen gas could occur at the expense of such simple inorganic electron donors as thiosulfate (Losada, Nozaki and Arnon 1961; Arnon, Losada, Nozaki and Tagawa 1960, 1961). We found in *Chromatium* a light-dependent transfer of electrons from thiosulfate or succinate not only to pyridine nucleotides but also to H^+ and N_2. The transfer of electrons to H^+, a reaction that is catalyzed by hydrogenase, results in photoproduction of hydrogen gas. The transfer of electrons to N_2 constitutes photofixation of N_2.

Experiments with cell-free systems of *R. rubrum* (Nozaki, Tagawa and Arnon, unpublished data) indicate that the noncyclic electron transport in photosynthetic bacteria that results in pyridine nucleotide reduction is coupled with formation of ATP. Experiments are now underway to determine whether the formation of ATP is also coupled with the noncyclic electron transport that results in the photoproduction of hydrogen or photofixation of nitrogen gas.

A diagrammatic representation of the proposed noncyclic electron flow mechanism in photosynthesis bacteria is shown in fig. 12. Three of the external electron acceptors have now been identified: pyridine nucleotides, nitrogen gas and protons. It seems likely that H^+ serves as an electron acceptor and hydrogen gas is evolved when electrons activated by light become surplus, i.e., when they are not consumed in metabolic reactions as in the reduction of CO_2 via pyridine nucleotides or in the photofixation of N_2.

15. **The Photoreductant in Plants: Noncyclic Photophosphorylation.** Photosynthetic bacteria can reduce pyridine nucleotide either with molecular hydrogen in the dark or with a less reduced electron donor, organic or inorganic, in the light. Green plants do not ordinarily contain hydrogenase, hence they cannot use hydrogen gas during photosynthesis for reducing pyridine nucleotide in the dark. They use water (OH^-) as the electron donor. The reduction of pyridine nucleotides with electrons donated by OH^- requires a considerable input of energy which in photosynthesis is supplied by light.

As already mentioned, isolated chloroplasts were known to reduce TPN in light with an accompanying evolution of oxygen. This was regarded as the physiological prototype of the Hill reaction in which non-physiological oxidants serve as electron acceptors. There was no evidence that this photochemical reduction of TPN was in any way linked with photosynthetic phosphorylation. Recently, however, the relation of photosynthetic phosphorylation to the photoreduction of TPN which at first seemed remote, was found to be direct (Arnon, Whatley and Allen 1957, 1958, Avron, Krogmann and Jagendorf 1958). In the presence of ADP and orthophosphate (P), the photoreduction of TPN and oxygen evolution was coupled with the formation of ATP in accordance with Equation 2.

$$2.\quad TPN + ADP + P + H_2O \xrightarrow{\text{light}} TPNH_2 + \tfrac{1}{2}\,O_2 + ATP$$

Under appropriate experimental conditions (Arnon, Whatley and Allen 1959) the evolution of one mole of oxygen was accompanied by the reduction of two moles of TPN, and the esterification of 2 moles of orthophosphate. The stoichiometry of this reaction was the same when TPN was replaced by ferricyanide (Equation 3).

$$3.\quad 2\,Fe^{3+}Cy + ADP + P + H_2O \longrightarrow 2\,Fe^{2+}Cy + \tfrac{1}{2}\,O_2 + ATP + 2\,H^+$$

With either TPN (Davenport 1959) or ferricyanide (Arnon, Whatley and Allen 1958, Jagendorf 1958) the rate of oxygen evolution is greatly increased when it is coupled with phosphorylation.

It was proposed elsewhere (Arnon 1959, 1961 a,b) that the reduction of TPN by chloroplasts in Reaction 2 involves a non-cyclic electron flow mechanism. Reaction 2 may thus be viewed as being analogous to the non-cyclic electron flow in bacteria fig. 12) and differing from it only in those aspects that reflect the special enzymatic composition of chloroplasts. Unlike photosynthetic bacteria, chloroplasts contain neither N_2 fixing enzymes nor hydrogenase. As a consequence, the electron acceptor end of the non-cyclic electron flow mechanism in chloroplasts can be coupled neither to photofixation of nitrogen nor to photoproduction of hydrogen gas, but only to CO_2 reduction (by way of $TPNH_2$).

The most characteristic difference between the non-cyclic electron flow mechanism of chloroplasts and bacteria is in the electron donor system. In chloroplasts the electron donor is water (i.e., OH^-) whereas bacteria, as already discussed, cannot use water but use inorganic or organic electron donors such as thiosulfate or succinate.

This interpretation of the difference between the non-cyclic electron flow mechanism in chloroplasts and in photosynthetic bacteria is supported by recent evidence. Vernon and Zaugg (1960), extending the earlier work of Vernon and Kamen (1954), have shown that chloroplasts which have lost, through aging or by poisoning, the capacity to photoevolve oxygen, are nevertheless able to photoreduce TPN with electrons donated by a reduced dye, 2, 6-dichlorophenol indophenol. (Operationally, the dye is supplied in catalytic amounts and kept in a reduced form by substrate amounts of added ascorbate). Krasnovsky [cf. review, (1960)] has found earlier that chlorophyll solutions in pyridine can bring about a photochemical electron transfer from ascorbate or other electron donors to pyridine nucleotides or other electron acceptors.

We have found recently (Losada, Whatley and Arnon 1961) that non-cyclic photophosphorylation in chloroplasts (Equation 2) can be experimentally separated into two distinct photochemical reactions (a) a photooxidation of water (OH^-) that yields oxygen (Equation 4) and (b) a non-cyclic photophosphorylation of the bacterial type, i.e., a photoreduction of triphosphopyridine nucleotide that is coupled with the formation of adenosine triphosphate (Equation 5). The two reactions have been separated by using reduced (A^-) and oxidized (A) indophenol dyes as summarized below:

$$4.\quad 2\,OH^- + 2A \xrightarrow{\text{light}} \tfrac{1}{2}O_2 + 2A^- + H_2O$$

$$5.\quad 2A^- + 2TPN + 2H^+ + ADP + H_3PO_4 \xrightarrow{\text{light}} TPNH_2 + ATP + 2A$$

$$\text{Sum: 2.}\quad TPN + ADP + H_3PO_4 + 2\,OH^- + 2H^+ \xrightarrow{\text{light}} ATP + 2TPNH_2 + \tfrac{1}{2}O_2 + H_2O$$

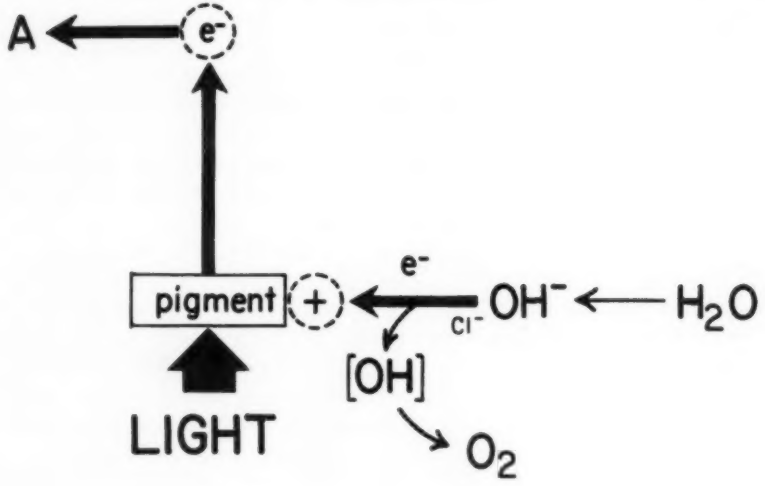
The "bacterial" type of non-cyclic electron flow mechanism that is envisaged as operating in chloroplasts, when the participation of water as the electron donor is blocked, is shown diagrammatically in fig. 13. The electron donor A^-, represents the reduced indophenol dye, and the electron acceptor B, represents TPN (cf., Equation 5). In accordance with previous formulations, we envisage the formation of adenosine triphosphate as occurring during the electron transport between cytochromes and chlorophyll (Arnon 1959, 1961 a, b.).

The photooxidation of water is diagrammatically represented in fig. 14. The reaction requires chloride. We regard the photooxidation of water by chloroplasts as an auxiliary reaction to supply electrons at an elevated re-

ducing potential for a second photochemical reaction, the bacterial type of non-cyclic photophosphorylation, during which a phosphorylation, coupled with the reduction of pyridine nucleotide, actually occurs (fig. 13).

It appears that non-cyclic photophosphorylation in green plants, combines two component photochemical reactions: (a) the auxiliary reaction for photooxidation of water (fig. 14) and (b) the bacterial type of non-cyclic photophosphorylation (fig. 13) that is used both by photosynthetic bacteria and by green plants for photoreduction of pyridine nucleotide and a coupled phosphorylation.

Fig. 15 depicts the combined scheme for non-cyclic photophosphorylation in green plants that we now envisage. The intermediate A in fig. 15



Photooxidation of water by green plants 14

Fig. 14. Scheme for photooxidation of water by chloroplasts. Details in the text.

is both the electron acceptor for the first, and the electron donor for the second light reaction (compare figs. 13 and 14). We have used indophenol dye as an experimental device to separate the two photochemical reactions. The natural intermediates with which the dyes have interacted have not been identified. They may include cytochromes or a quinone (Bishop 1959).

Under physiological conditions, when the electron acceptor B (fig. 15) is TPN, non-cyclic photophosphorylation in chloroplasts (Equation 2) produces ATP and a strong reductant, $TPNH_2$, having a normal redox

potential $E'_o = 0.324$ v. Under non-physiological conditions when B is not TPN but a more oxidized electron acceptor such as ferricyanide ($E'_o = 0.360$ v.), a considerable amount of absorbed light energy (equivalent to a redox potential of 684 millivolts) is lost. ATP (also oxygen) is produced in the same ratio to the number of electrons transferred, but the reductant formed is no longer $TPNH_2$ but ferrocyanide.

Under special conditions, oxygen gas ($E'_o = 0.815$ v. for the water/oxygen system) can also replace TPN as the electron acceptor B (fig. 15) in cell-free systems. The energy loss here is even greater (equivalent to a redox potential of 1139 millivolts) than in the ferricyanide reaction; ATP is again formed but the "reductant" produced is now water instead of

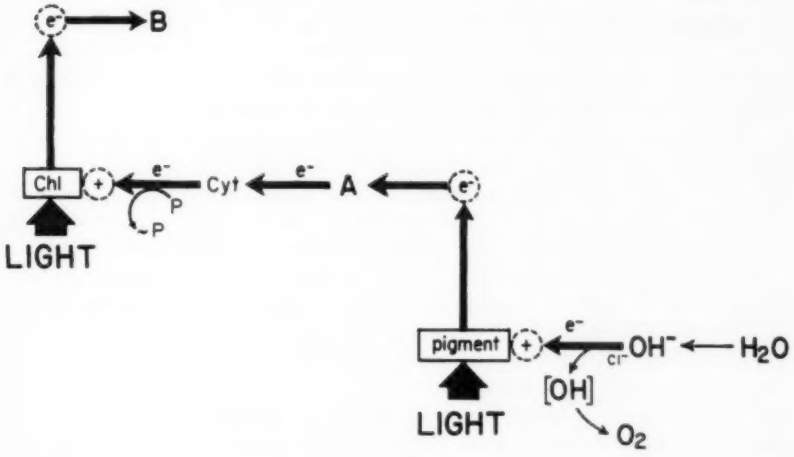


Fig. 15. Scheme for noncyclic photophosphorylation in green plants. Details in the text.

$TPNH_2$. If, at the same time that oxygen is used as the electron acceptor B, water is used as the electron donor (bottom of fig. 15), the resultant evolution of oxygen at one end would balance the oxygen consumption at the other. An oxygen exchange reaction would result, without any net consumption of oxygen that could be measured manometrically: oxygen would act as a catalyst. This would explain the catalytic effect of oxygen which we observed in our first experiments on photosynthetic phosphorylation (Arnon, Allen and Whatley, 1954), [compare also "oxygen-catalyzed" cyclic photophosphorylation (Arnon 1961 a, b)].

Molecular oxygen can also serve as the electron acceptor B in an experi-

mentally contrived "bacterial type" of noncyclic photophosphorylation by chloroplasts (fig. 13), i.e., when the use of water as the electron donor is blocked by inhibitors (Vernon and Zaugg 1960, Krogmann and Vennesland 1959). Under these conditions ATP formation would be accompanied by the simultaneous consumption of O_2 and of an external electron donor ($^-A^-$ in fig. 13). An apparent "oxidative photosynthetic phosphorylation" would result (Krogmann and Vennesland 1959) that superficially resembles oxidative phosphorylation by mitochondria. There is no experimental evidence, however, that under physiological conditions molecular oxygen is a reactant in photosynthetic phosphorylation by chloroplasts.

Present evidence (Arnon 1961 a, b) suggests that, in contrast to oxidative phosphorylation by mitochondria, the intervention of molecular oxygen in photosynthetic phosphorylation by chloroplasts is an energy-wasteful step. A more efficient conversion of absorbed light energy occurs under anaerobic conditions, in the presence of catalytic amounts of cofactors (Arnon, Losada, Whatley, Tsujimoto, Hall and Horton, 1961).

The current concept of non-cyclic photophosphorylation in green plants is a further elaboration, in the light of new experimental findings, of the one presented earlier (Arnon 1959). It is now possible to envisage in more detail the electron transfer reactions from water (OH^-) that result in oxygen evolution. We had first suggested that this may be a dark reaction between water (OH^-) and a cytochrome component peculiar to green plants (Arnon 1959). Such a reaction, although it appeared thermodynamically possible, could not be described in terms of the properties of the presently known cytochrome constituents of green cells (Hill and Bendall 1960). We next suggested that the interaction between OH^- and cytochromes may require an additional input of energy (Arnon 1961a) and now it appears that this energy is supplied by an auxiliary light reaction. This auxiliary light reaction is found in green plants but not in photosynthetic bacteria, and explains why photosynthesis is accompanied by an evolution of oxygen only in green plants.

The separation of photooxidation of water from the photophosphorylation reaction is consistent with the view that photosynthesis in green plants involves the participation of more than one light reaction. Warburg, Krippahl and Schroeder (1955) found in *Chlorella* and enhancement of photosynthesis at red light by the addition of *catalytic* amounts of blue light and attributed this effect to photoactivation of a photosynthetic enzyme ("Luminoferment"). The maximum effectiveness of the catalytic light was at 460 mμ. More directly related to our experiments are those of Emerson, Chalmers, and Cederstrand (1957) who observed an enchancement of photosynthesis in *Chlorella* at red light by light of shorter wave length, but here the supplementary light was not catalytic but of an intensity "suf-

ficient to give measurable photosynthesis." Emerson and Chalmers (1958) found the maximum effectiveness of the supplementary light in *Chlorella* at 480 mμ and a lower peak of effectiveness at about 655 mμ, coinciding approximately with the maximum absorption peaks of chlorophyll b.

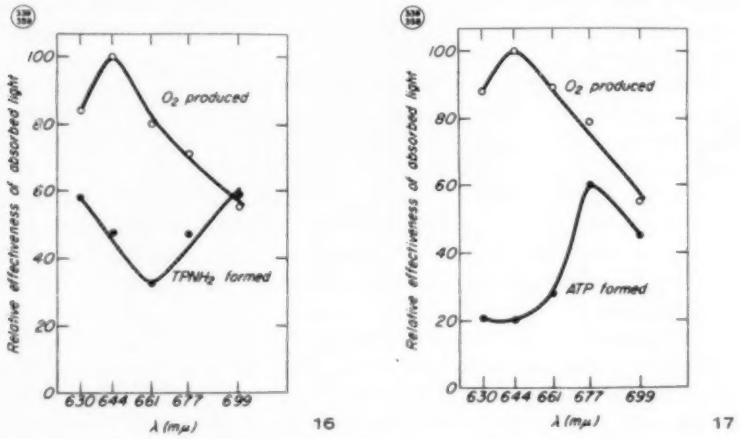
Emerson and Chalmers (1958) suggested from these and similar observations with other algae that, at the long wavelengths of light absorbed only by chlorophyll a, full efficiency of photosynthesis depends on the absorption of light of shorter wavelength by an accessory photosynthetic pigment: chlorophyll b in *Chlorella,* or phycobilins in other algae. The supplementary light in this view is not used as a catalyst but is consumed as a substrate.

The enhancement effect of supplementary light has been confirmed by Myers and French (1959), Blinks (1960) and Govindjee, Thomas and Rabinowitch (1960). Of special relevance to our concept is the conclusion of Myers and French (1959) that their results favor "the idea that the interaction (of the light absorbed by chlorophyll a and b) takes place between chemical products of two separate reactions initiated by light" and the report of Govindjee, Thomas and Rabinowitch (1960) that the enhancement effect is associated with the oxygen-liberating mechanism rather than with CO_2 reduction.

The involvement of two light reactions with the participation of water in the photosynthetic cytochrome system of both green plants and photosynthetic bacteria has been postulated by Hill and Bendall (1960). However, our findings support the conclusion that green plants possess a special photochemical reaction, photooxidation of water, that is absent in photosynthetic bacteria.

We have not identified the "pigment," shown in fig. 14 and 15, that is involved in the photooxidation of water. Recent experiments (Arnon, Losada, Whatley, Tsujimoto, Hall and Horton, 1961) on the effectiveness of monochromatic light on the photochemical reactions of chloroplasts suggest that this pigment is more likely to be chlorophyll b or an accessory pigment that is found only in higher plants and algae, rather than chlorophyll a (or the closely related bacteriochlorophyll) found in all photosynthetic cells. In the red region of the spectrum the photooxidation of water was most effective around 644 mμ, which corresponds to the maximum absorption peak (French 1960) in the red for chlorophyll b (figs. 16 and 17). The effectiveness of monochromatic light in the red region on photoreduction of TPN and cyclic photophosphorylation was distinctly different from that on oxygen evolution (figs. 16 and 17), thus supporting the view that these are different light reactions. The experiments with monochromatic light favor the conclusion that the photochemical reaction which produces oxygen is different from the photochemical production of ATP and reduced pyridine nucleotide.

16. **Energy Conversion as a Unifying Concept in Photosynthesis.** The concept of photosynthesis to which we were led in the six years since the process was first completely localized in isolated chloroplasts differs from the conventional view that photosynthesis is mainly a process of CO_2 assimilation. Photosynthesis appears to be first and foremost a process for converting sunlight into chemical energy and this conversion is more directly associated with phosphorus than with carbon assimilation. In the light of present knowledge, photosynthesis may be defined as the synthesis



Figs. 16–17.—Fig. 16. Effectiveness of monochromatic light, in the red region of the spectrum on oxygen evolution and TPN reduction by isolated chloroplasts. 100 on the ordinate scale is equivalent to 0.15μ atoms oxygen evolved per μ mole quanta of light absorbed. 58 on the ordinate scale is equivalent to 0.09μ moles $TPNH_2$ formed per μmole quanta of light absorbed. Oxygen was measured manometrically when the photochemical reaction was limited to the photooxidation of OH^- (Equation 4). TPN reduction (measured spectrophotometrically at 340 mμ) was carried out in a parallel experiment in which the electron donor for TPN reduction was not OH^- but ascorbate (cf. A^- in Equation 5).—Fig. 17. Effectiveness of monochromatic light, in the red region of the spectrum, on oxygen evolution and cyclic photophosphorylation by isolated chloroplasts. 100 on the ordinate scale is equivalent to 0.16 μatoms oxygen evolved per μmole quanta of light absorbed. 60 on the ordinate scale is equivalent to 0.10 μmole ATP formed per μmole quanta of light absorbed. Oxygen evolution was measured as in Fig. 16. ATP formation by cyclic photophosphorylation was measured in a parallel experiment, under anaerobic conditions, using vitamin K_3 as a catalyst (Equation 1).

of cellular substances at the expense of chemical energy formed by photochemical reactions. This definition includes, but is not limited to, CO_2 assimilation.

In both bacterial and plant photosynthesis the photosynthetic events proper are limited to the formation of adenosine triphosphate and reduced pyridine nucleotide by cyclic and non-cyclic photophosphorylation. This transformation of light into the common currency of cellular energy is

fundamentally independent of carbon dioxide assimilation. There is no particular reason why adenosine triphosphate or a photochemically generated reductant could not be used for driving endergonic cellular processes other than CO_2 assimilation.

The photoassimilation of acetate by *Chromatium* is a case of photosynthesis without either oxygen evolution or CO_2 reduction (Losada, Trebst, Ogata and Arnon 1960, Stanier, Doudoroff, Kunisawa and Contopoulou 1960, Stanier 1961). So is the light dependent conversion of glucose into starch (Machlachlan and Porter, 1959). Other manifestations of the photosynthetic process, now under active investigation, are the photofixation of nitrogen and the photoproduction of hydrogen gas. Usually, these reactions would be considered as being distinct from photosynthesis proper, but according to our present concept these examples represent photosynthetic events because they are being driven by light energy. All these light-driven reactions are also known to occur in the dark in nonchlorophyllous cells, but in this respect they resemble "photosynthetic" CO_2 assimilation which occurs, by essentially the same pathway, in nonphotosynthetic bacteria.

In this view of photosynthesis, CO_2 assimilation, although quantitatively the dominant form of photosynthesis on our planet, is fundamentally only a special case of the use and storage of light energy. CO_2 assimilation proper, in both green plants and photosynthetic bacteria, consists of exclusively dark reactions that are not peculiar to photosynthesis—a conclusion that was also reached by investigators of the carbon path in photosynthesis. Thus Calvin (1959b) wrote recently: "The reduction of carbon dioxide, we now have every reason to suppose, occurs in a series of reactions which can take place entirely in the dark. In fact, all the enzyme systems that we now know participate in the conversion of CO_2 to carbohydrates have been found in a wide variety of organisms, many of which are not photosynthetic."

The familiar accumulation of carbon compounds as carbohydrates during photosynthesis in green plants constitutes storage of trapped light energy and is fundamentally extraneous to the energy conversion process itself. The first chemically identified products of photosynthesis in green plants are now known to be ATP and $TPNH_2$. They are present, however, in the cell only in catalytic amounts and cannot be stored to any appreciable degree for future use; they are promptly consumed in the synthesis of carbohydrates, fats, proteins and other cellular constituents.

The proposal that ATP formation is a fundamental event in photosynthesis has been made earlier, notably by Emerson, Stauffer and Umbreit (1944) but, as was recently pointed out by Umbreit (1960), "the early experiments were not adequate to demonstrate it." Without sufficient experimental evidence, the early theoretical proposals of Umbreit and his associates could not be adequately defended against the theoretical ob-

jections leveled against them [as for example by Rabinowitch (1945, p. 229)], particularly since several years later the first experiments with P^{32} to test the occurrence of light-induced phosphorylation in cell-free systems led to negative results. Aronoff and Calvin (1948), who made these experiments with spinach grana, reported that "there is no direct connection between light and the gross formation of organic phosphorus compounds."

17. **Photosynthesis and Biochemical Evolution.** The insight into the mechanism of photosynthesis, gained from cell-free experiments with cloroplasts and chromatophores, permits us to interpret, with somewhat enchanced confidence, certain aspects of biochemical evolution which we have already discussed elsewhere (Arnon, Whatley and Allen 1958, Losada, Trebst, Ogata and Arnon 1960).

The beginning of photosynthesis may be viewed as an emergence of a porphyrin that gave rise to chlorophyll and permitted the cell to use for metabolic purposes the energy of sunlight. This primitive photosynthesis consisted only of anaerobic cyclic photophosphorylation. This would be the case for example, with such reduced carbon compounds as acetate that might have been present in the primitive environment. When CO_2 became the source of carbon, no photochemically formed reductant was required as long as hydrogen gas was present in the atmosphere. Oparin (1957) and Miller and Urey (1959) have summarized the evidence that in the early periods of evolution of life forms, the environment contained simple carbon compounds such as acetate and hydrogen gas. This primitive type of photosynthesis is still seen today in photosynthetic bacteria. *Chromatium*, for example, is capable of using external hydrogen gas for reducing, in the dark, the pyridine nucleotide that is needed for CO_2 assimilation, or of photoassimilating acetate without the aid of any external reductants.

The harnessing of light energy for the synthesis of ATP was an event of supreme importance to the cell. It provided the cell, in an *anaerobic environment*, a much more efficient mechanism than fermentation for the formation of ATP that was needed for the transformation of existing carbon compounds into fats, carbohydrates, proteins, etc. Cyclic photophosphorylation made ATP synthesis independent of external substrates, i.e., external electron donors and electron acceptors. In their place, the photosynthetic apparatus generated endogenously, at the expense of absorbed light, a continuous flow of electrons the transport of which was coupled with the formation of ATP. Cyclic photophosphorylation gave the photosynthetic cell, living in an atmosphere devoid of oxygen gas, a mechanism for ATP formation that was at least as effective as the process of oxidative phosphorylation that became possible later in the evolutionary time scale, when the atmosphere contained oxygen gas.

As hydrogen gas vanished from the primitive atmosphere, the photosynthetic cell probably became dependent on the photosynthetic apparatus for generating photochemically a reductant for CO_2 assimilation from such electron donors as succinate or thiosulfate. Light energy now would have served a dual purpose. It would supply adenosine triphosphate by cyclic photophosphorylation and it would provide electrons for reducing pyridine nucleotides by a non-cyclic electron flow mechanism. In organisms which contain, or can adaptively form, hydrogenase or nitrogenase (photosynthetic bacteria and algae), this phase of photosynthesis can also be observed today as a photoproduction of molecular hydrogen or a photofixation of nitrogen gas.

The non-cyclic electron flow mechanism in photosynthetic bacteria uses as electron donors reduced sulfur compounds or organic acids. Water (OH^-) became an electron donor only with the emergence of plant photosynthesis. It now appears that this event was made possible, because plants have evolved an auxiliary light-dependent reaction, in which the electrons from water (OH^-) are first raised to a reducing potential similar to that of the electron donors in bacterial photosythesis, and are then used in a second photochemical reaction—the non-cyclic electron flow common to plants and bacteria—in which pyridine nucleotide reduction is coupled with the formation of adenosine triphosphate.

Oxygen evolution is peculiar to green plants because it is the product of an auxiliary photochemical reaction, the oxidation of water (OH^-), that is found only in green plants. Water as an electron donor is, therefore, not involved in the two main events of non-cyclic photophosphorylation in plants and bacteria, the photoreduction of pyridine nucleotide and the coupled formation of ATP.

Photooxidation of water enabled green plants to form a CO_2 reductant at the expense of light energy with the aid of an ubiquitous substance, water, and in this way to invade and live autotrophically in areas devoid of reduced sulfur compounds or of other electron donors of restricted distribution. The resultant proliferation of plant growth was responsible for releasing to the atmosphere the oxygen, locked in the water molecule, by the only known important mechanism capable of accomplishing this, photosynthesis of green plants (Oparin, 1957 Miller and Urey 1959).

Once molecular oxygen became available, the way was open for biochemical evolution to progress toward aerobic metabolism. The oxygen-independent cyclic photophosphorylation by chlorophyll-containing particles could now be paralleled by an efficient biological utilization of the energy of chemical substrates through the mechanism of oxidative phosphorylation of mitochondria. Photosynthesis of green plants now provided both the organic substrates and oxygen to make oxidative phosphorylation and aerobic life on this planet possible.

An interesting aspect of the relation between photosynthetic and oxidative phosphorylation in biochemical evolution is the common phylogenetic relationship between proplastids and mitochondria, as it was recently recently reported by Mühlethaler and Frey-Wyssling (1959). Their observations on proplastid development in embryonic cells suggest that mitochondria followed rather than preceded chloroplasts as functional organelles in cellular metabolism. This is in harmony with the biochemical evidence, since photosynthetic phosphorylation by chlorophyll-containing particles, being independent of molecular oxygen, could occur before oxidation phosphorylation by mitochondria, which requires molecular oxygen (Arnon, Whatley and Allen, 1958).

Thirty-five years ago, a great physical chemist, the late G. N. Lewis, wrote "that living creatures are cheats in the game of physics and chemistry. . . . They alone seem able to breast the great stream of apparently irreversible process. Those processes tear down, living things build up. While the rest of the world seems to move toward a dead level of uniformity, the living organism is evolving new substances and more intricate forms" (Lewis, 1926). It would seem that only when a living organism dies does it join the universal march toward increased entropy (disorder) in which energy always becomes more dissipated and materials pass from more organized states to more mixed-up states.

But the evolution of life on this planet to its present level of complexity and organization has occurred not because life found a way of evading the universal tendency to energy dissipation and disorder that is expected from the second law of thermodynamics, but because life has been tied to the energy conversion process of photosynthesis. The energy of the sun is being continuously dissipated and in this way the Second Law retains its validity for our planet as a whole. But through photosynthesis, life has found a way of using the "improbable transition forms" of sun's energy for its own activities on which growth and function depend. In this manner life has formed local situations where the second law *appears* not to be observed. The understanding of the nature of the energy conversion process in photosynthesis is thus a part of the intellectual emancipation of man by helping him to understand how the living world has developed in harmony with the laws of physics and chemistry.

Literature Cited

Allen, M. B., D. I. Arnon, J. B. Capindale, F. R. Whatley, and **L. J. Durham.** 1955. Photosynthesis by isolated chloroplasts III. Evidence for complete photosynthesis. Jour. Amer. Chem. Soc. **77**: 4149–4155.

————, **F. R. Whatley,** and **D. I. Arnon.** 1958. Photosynthesis by isolated chloroplasts. VI. Rates of conversion of light into chemical energy in photosynthetic phosphorylation. Biochim. Biophys. Acta **27**: 16–23.

Anderson, I. C., and **R. C. Fuller.** 1958. Photophosphorylation by isolated chromatophores of the purple sulfur bacteria. Arch. Biochem. Biophys. **76:** 168–179.

Arnon, D. I. 1951. Extracellular photosynthetic reactions. Nature (Lond.) **167:** 1008–1010.

————. 1955. The chloroplast as a complete photosynthetic unit. Paper presented at the Cell Symposium, American Association for the Advancement of Science, Berkeley Meeting 1954. Science **122:** 9–16.

————. 1956a. Phosphorus metabolism and photosynthesis. Ann. Rev. Pl. Physiol. **7:** 325–354.

————. 1956b. Localization of photosynthesis in chloroplasts. *In: Enzymes: Units of Biological Structure and Function,* O. H. Gaebler, Ed., pp. 279–313, Academic Press, New York.

————. 1959. Conversion of light into chemical energy in photosynthesis. Nature **184:** 10-21.

————. 1960. The chloroplast as a functional unit in photosynthesis. *In: Handbuch der Pflanzenphysiologie,* Vol. V, Part I, W. Ruhland, Ed., pp. 773–829, Springer, Heidelberg.

————. 1961a. Cell-free photosynthesis and the energy conversion process. *In: Light and Life,* W. D. McElroy and B. Glass, Eds., pp. 489–569, Johns Hopkins Press, Baltimore.

————. 1961b. Photosynthetic phosphorylation and the energy conversion process in photosynthesis. *In: Biological Structure and Function.* T. W. Goodwin and O. Lindberg, Eds., Academic Press (In Press).

————, **M. B. Allen,** and **F. R. Whatley.** 1954. Photosynthesis by isolated chloroplasts. Nature (Lond.) **174:** 394–396.

————, ———— and ————. 1956. Photosynthesis by isolated chloroplasts. IV. General concept and comparison of three photochemical reactions. Biochim. Biophys. Acta **20:** 449–461.

————, ————, ————, **J. B. Capindale.** and **L. L. Rosenberg,** 1955. Photosynthesis by isolated chloroplasts. Proc. 3rd Int. Congress Biochem., Brussels. Pp. 227–232.

————, **M. Losada, M. Nozaki,** and **K. Tagawa.** 1960. Photofixation of nitrogen and photoproduction of hydrogen by thiosulfate during bacterial photosynthesis. Biochem. Jour. **77:** 23P.

————, ————, ————, and ————. 1961. Photoproduction of hydrogen, photofixation of nitrogen gas and a unifying concept of photosynthesis. Nature **190:** 601–606.

————, ————, **F. R. Whatley, H. Y. Tsujimoto, D. O. Hall and A. A. Horton.** 1961. Photosynthetic phosphorylation and molecular oxygen. Proc. Nat. Acad. Sci. (U. S.) **47.**

————, **F. R. Whatley** and **M. B. Allen.** 1954. Photosynthesis by isolated chloroplasts. II. Photosynthetic phosphorylation, the conversion of light into phosphate bond energy Jour. Am. Chem. Soc. **76:** 6324–6329.

————, ————, and ————. 1955. Vitamin K as a cofactor of photosynthetic phosphorylation. Biochim. Biophys. Acta **16:** 607–608.

————, ————, and ————. 1957. Triphosphopyridine nucleotide as a catalyst of photosynthetic phosphorylation. Nature **180:** 182–185.

————, ————, and ————. 1958. Assimilatory power in photosynthesis. Science **127:** 1026–1034.

————, ————, and ————. 1959. Photosynthesis by isolated chloroplasts. VIII. Photosynthetic phosphorylation and the generation of assimilatory power. Biochim. Biophys. Acta **32:** 47–57.

Aronoff, S., and **M. Calvin.** 1948. Phosphorus turnover and photosynthesis. Pl. Physiol. **23**: 351–358.

Aubert, J. P., G. Milhaud and **J. Millet.** 1957. L'assimilation de l'anhydride carbonique par des bacteries chimiautotrophes. Ann. Inst. Pasteur **92**: 515–528.

Avron, M., and **A. T. Jagendorf.** 1957. An extractable factor in photosynthetic phosphorylation. Nature **179**: 428–429.

————, **D. W. Krogmann,** and **A. T. Jagendorf.** 1958. The relation of photosynthetic phosphorylation to the Hill reaction. Biochim. Biophys. Acta **30**: 144–153.

Bassham, J. A., A. A. Benson, L. D. Kay, A. Z. Harris, A. T. Wilson and **M. Calvin.** 1954. The path of carbon in photosynthesis. XXI. The cyclic regeneration of carbon dioxide acceptor. Jour. Am. Chem. Soc. **76**: 1760–1770.

————, and **M. Calvin.** 1956. Photosynthesis. *In: Currents in Biochemical Research*, D. E. Green Ed., Interscience, New York.

Bishop, N. I. 1959. The reactivity of a naturally occurring quinone (Q-255) in photochemical reactions of isolated chloroplasts. Proc. Nat. Acad. Sci. (U. S.) **45**: 1696–1702.

Blinks, L. R. 1960. Action spectra of chromatic transients and the Emerson effect in marine algae. Proc. Nat. Acad. Sci. (U. S.) **46**: 327–333.

Boltzmann, L. 1886. Der Zweite Hauptsatz der mechanischen Wärmetheorie. See p. 39 *in Populäre Schriften*, Barth, Leipzig, 1905.

Boychenko, E. A., and **V. I. Baranov.** 1954. Participation of organic compounds of iron in photoreduction of CO_2 by isolated chloroplasts. Doklady Akad. Nauk S.S.S.R. **95**: 1025–1027; Chem. Abstr. **48**: 8881.

Brown, A. H., and **J. Franck.** 1948. On the participation of carbon dioxide in the photosynthetic activity of illuminated chloroplast suspensions. Arch. Biochem. **16**: 55–60.

Calvin, M. 1956. The photosynthetic carbon cycle. Proc. 3rd Int. Cong. Biochem., Brussels, 1955. pp. 211–225, Academic Press Inc., New York.

————. 1959a. Energy reception and transfer in photosynthesis. *In:* Reviews of Modern Physics **31**: 147–156; also in *Biophysical Science—A Study Program*, J. C. Oncley, Ed., pp. 147–156, J. Wiley and Sons, New York.

Calvin, M. 1959b. Evolution of enzymes and the photosynthetic apparatus. Science **130**: 1170–1174.

Chow, C. T., and **B. Vennesland.** 1957. Photosynthetic phosphorylation by chloroplast fragments. Pl. Physiol. **32**: (Supp): iv.

Davenport, H. E. 1959. Coenzyme reduction by illuminated chloroplasts. Biochem. Jour. **73**: 45P.

Emerson, R. and **R. V. Chalmers** 1958. Speculations concerning the function and phylogenetic significance of the accessory pigments of algae. Phycolog. Soc. Am. News Bull. **11**: 51–56.

————, ————, and **C. Cederstrand.** 1957. Some factors influencing the long-wave limit of photosynthesis. Proc. Nat. Acad. Sci. (U. S.) **43**: 133–143.

Emerson, R. L., J. F. Stauffer and **F. F. Umbreit.** 1944. Relationships between phosphorylation and photosynthesis in *Chlorella*. Am. Jour. Bot. **31**: 107–120.

Engelmann, Th. W. 1883. Bacterium photometricum. Pflügers Arch. ges. Physiol. **30**: 95–124.

————. 1888. Die Purpurbacterien und ihre Beziehungen zum Licht. Bot. Zeit. **46**: 661 ff. (Reprinted pages 1–50).

Esau, K. 1953 Plant Anatomy. J. Wiley and Sons, New York.

French, C. S. 1960. The chlorophylls *in vivo* and *in vitro*. *In: Handbuch der Pflanzenphysiologie*, vol. V, part I (Edited by W. Ruhland) pp. 262–297, Springer, Heidelberg.

Frenkel, A. W. 1954. Light induced phosphorylation by cell-free preparations of photosynthetic bacteria. Jour. Am. Chem. Soc. **76:** 5568–5569.

————. 1956. Photophosphorylation of adenine nucleotides by cell-free preparations of purple bacteria. Jour. Biol. Chem. **222:** 823–834.

————. 1958. Light-induced reactions of chromatophores of *Rhodospirillum rubrum*. U. S. Brookhaven Symp. Biol. **11:** 276–288.

————, and **R. Lewin.** 1954. Photoreduction by *Chlamydomonas*. Am. Jour. Bot. **41:** 586–589.

Gaffron, H. 1939. Reduction of carbon dioxide with molecular hydrogen in green algae. Nature **143:** 204–205.

————. 1944. Photosynthesis, photoreduction and dark reduction of carbon dioxide of certain algae. Biol. Rev. **19:** 1–20.

————. 1954. Mechanism of photosynthesis. *In: Autotrophic Microorganisms*, B. A. Fry and J. L. Peel, Eds., p. 163, Cambridge University Press.

————, Ed. 1957. *Research in Photosynthesis*. Interscience, New York.

Geller, D. M. 1957. Photophosphorylation by *Rhodospirillum rubrum* preparations. Doctoral dissertation, Div. Med. Sci., Harvard Univ. Press.

Gest, H., and **M. D. Kamen.** 1960. The photosynthetic bacteria. *In: Handbuch der Pflanzenphysiologie*, Vol. V, Part 2, W. Ruhland, Ed., pp. 568–612, Springer Heidelberg.

Govindjee, R., J. B. Thomas and **E. Rabinowitch.** 1960. "Second Emerson Effect" in the Hill reaction of *Chlorella* cells with quinone as oxidant. Science **132:** 421.

Hansen A. 1882. Geschichte der Assimilation und Chlorophyllfunction. Arbeit. Bot. Inst. Würzburg **2:** 537–626.

Heath, O. V. S. and **B. Orchard.** 1957. Midday closure of stomata. Nature **180:** 180–181.

Hill, R. 1951. Reduction by chloroplasts. Sym. Soc. Exp. Biol. **5:** 223–231.

———— and **F. Bendall.** 1960. Function of the two cytochrome components in chloroplasts: a working hypothesis. Nature **186:** 136–137.

Holmyard, E. J. 1931. *Makers of Chemistry*. Clarendon Press, Oxford.

Ingenhousz, J. 1796. *Essay on the food of plants and the renovation of soils*. London.

Jagendorf, A. T. 1958. The relationship between electron transport and phosphorylation in spinach chloroplasts. U. S. Brookhaven Symp. Biol. **11:** 236–258.

————, and **M. Avron.** 1958. Cofactors and rates of photosynthetic phosphorylation by spinach chloroplasts. Jour. Biol. Chem. **231:** 277–290.

————, and ————. 1959. Inhibitors of photosynthetic phosphorylation in relation to electron and oxygen transport pathways of chloroplasts. Arch. Biochem. Biophys. **80:** 246–257.

Jakoby, E. B.. D. O. Brummond, and **S. Ochoa.** 1956. Formation of 3-phosphoglyceric acid by carbon dioxide fixation with spinach leaf enzymes. Jour. Biol. Chem. **218:** 811–822.

James, W. O., and **V. S. Das.** 1957. The organization of respiration in chlorophyllous cells. New Phytol. **56:** 325–343.

Kamen, M., and **J. W. Newton.** 1957. Photophosphorylation by subcellular particles from *Chromatium*. Biochim. Biophys. Acta **25:** 462–474.

Karunairatnam, M. C., and **H. Gest.** 1958. Hydrogenase and photometabolism in *Rhodospirillum rubrum*. Abstracts, VIIth Internat. Congr. Microbiol., p. 74–75, Almquist and Wiksells, Uppsala.

Korkes, S. 1955. Enzymatic reduction of pyridine nucleotides by molecular hydrogen. Jour. Biol. Chem. **216:** 737–747.

Kornberg, A. 1960. Biologic synthesis of deoxyribonucleic acid. Science **131:** 1503–1508.

Krasnovsky, A. A. 1960. The primary processes of photosynthesis in plants. Annu. Rev. Pl. Physiol. **11:** 363–410.

Krogmann, D. W., and **B. Vennesland** 1959. Oxidative photosynthetic phosphorylation by spinach chloroplasts. Jour. Biol. Chem. **234:** 2205–2210.

Lebedev, A. 1907. Uber die Assimilation des Kohlenstoffes bei Wasserstoffoxydierenden Bakterien. Biochem. Zeit. **7:** 1–10.

————. 1909. Uber die Assimilation des Kohlenstoffes bei Wasserstoffoxydierenden Bakterien. Ber. Deutsch. Bot. Ges. **27:** 598–602.

————. 1921. The assimilation of carbon by saprophytes. Izvestiya Donskovo gosudarstvenno universiteta **3:** 25–55; translation published in Am. Rev. Soviet Medicine **5:** 15–27 (1948).

Lehninger, A. L. 1955. Oxidative phosphorylation. The Harvey Lectures **49:** 176–216, Academic Press, New York.

Lewis, G. N. 1926. *The Anatomy of Science.* Yale University Press, New Haven.

————, and **D. Lipkin.** 1942. Reversible photochemical processes in rigid media: the dissociation of organic molecules into radicals and ions. Jour. Am. Chem. Soc. **64:** 2801–2808.

Lipmann, F. 1941. Metabolic generation and utilization of phosphate bond energy. Adv. Enzymol. **1:** 99–162.

Livingston, R. 1960. The photochemistry of chlorophyll. *In: Handbuch der Pflanzenphysiologie.* W. Ruhland, Ed., Vol. V. Part I, p. 832, Springer, Heidelberg.

Losada, M., M. Nozaki, and **D. I. Arnon** 1961. Photoproduction of molecular hydrogen from thiosulfate by *Chromatium* cells. *In: Light and Life,* W. D. McElroy and B. Glass, Eds., p. 570–575, Johns Hopkins Press, Baltimore.

————, **A. V. Trebst,** and **D. I. Arnon.** 1960. Photosynthesis by isolated cloroplasts. XI. CO_2 assimilation in a reconstituted chloroplast system. Jour. Biol. Chem. **235:** 832–839.

————, ————, **S. Ogata,** and **D. I. Arnon.** 1960. Equivalence of light and adenosine triphosphate in bacterial photosynthesis. Nature **186:** 753–760.

————, **F. R. Whatley,** and **D. I. Arnon.** 1961. Separation of two light reactions in noncyclic photophosphorylation of green plants. Nature **190:** 606–610.

Lumry, R., J. D. Spikes, and **H. Eyring.** 1954. Photosynthesis. Annu. Rev. Pl. Physiol. **5:** 271–340.

Maclachlan, G. A., and **H. K. Porter.** 1959. Replacement of oxidation by light as the energy source for glucose metabolism in tobacco leaf. Proc. Roy. Soc. London **B150:** 460–473.

Mayer, J. R. 1845. Die Organische Bewegung. *In: Mechanik der Wärme,* p. 54, J. G. Cotta, Stuttgart, 1874.

Miller, S. L., and **H. C. Urey.** 1959. Organic compound synthesis on the primitive earth. Science **130:** 245–251.

Mühlethaler K. and **A. Frey-Wyssling.** 1959. Entwicklung und Struktur der Proplastiden. Jour. Biophys. Biochem. Cytol. **6:** 507–512.

Müller, F. M. 1933. On the metabolism of purple sulfur bacteria in organic media. Ark. Mikrobiol. **4:** 131–166.

Myers, J., and **C. S. French.** 1959. A specific participation of chlorophyll *b* in photosynthesis. Carnegie Inst. of Washington Yearb. **58:** 318–323.

Nakamoto, T., D. W. Krogmann, and **B. Vennesland.** 1959. The effect of oxygen on riboflavin phosphate-dependent photosynthetic phosphorylation by spinach chloroplasts. Jour. Biol. Chem. **234:** 2783–2788.

Ogata, S., M. Nozaki, and **D. I. Arnon.** 1959. Reported by D. I. Arnon at Symposium on Comparative Biochemistry of Photoreactive Pigments, Pacific Grove, Calif.

Oparin A. I. 1957. *The Origin of Life on Earth.* Third Ed., Academic Press, New York.

Pasteur, L. 1866. Claude Bernard. Idée de l'importance de ses travaux, de son enseignement et de sa méthode. Moniteur universal, Nov. 7, p. 1284–1285. Reprinted in Oeuvres de Pasteur, v. II, p. 487, P. Vallery-Radot, Ed., Masson, Paris. 1922.

Peck, H. D., and **H. Gest.** 1954. Enzymic reduction of pyridine nucleotides by molecular hydrogen. Biochim. Biophys. Acta **15:** 587–588.

Petrack, B. 1959. Photophosphorylation in cell free preparations of blue-green algae. Federation Proc. **18:** 302.

Pfeffer. W. 1900. *Physiology of Plants.* Clarendon Press, Oxford.

Priestley, J. 1774. *Experiments and Observations on Different Kinds of Air.* Vol. I. J. Johnson, London.

————. 1777. *Experiments and Observations on Different Kinds of Air.* Vol. III. J. Johnson, London.

————. 1779. *Experiments and Observations Relating to Various Branches of Natural Philosophy; with a Continuation of the Observations on Air.* Vol. I, pp. 296–302. J. Johnson, London.

Rabinowitch, E. I. 1945. *Photosynthesis and Related Processes,* Vol. 1. Interscience, New York.

————. 1953. Progress in photosynthesis. Sci. Am. **189:** 80–81 (November).

————. 1956. *Photosynthesis,* Vol. II, Part 2. Interscience, New York.

Racker, E. 1955. Synthesis of carbohydrates from carbon dioxide and hydrogen in a cell-free system. Nature **175:** 249–251.

————. 1957. The reductive pentose phosphate cycle. I. Phosphoribulokinase and ribulose diphosphate carboxylase. Arch. Biochem. Biophys. **69:** 300–310.

————. 1958. Personal communication.

Reed, H. S. 1949. "Jan Ingenhousz." Chron. Bot. **11:** 285–396.

Roelofsen, P. A. 1934. On the metabolism of the purple sulfur bacteria. Proceed. Konink. acad. Wetsenchappen **37:** 660–668.

Ruben, J. 1943. Photosynthesis and phosphorylation. Jour. Am. Chem. Soc. **65:** 279–282.

De Saussure, T., 1804. Recherches chimiques sur la vegetation. V. Nyon, Paris.

Sachs, J. 1887. *Lectures on the Physiology of Plants.* Clarendon Press, Oxford.

Smillie, R. M., and **R. C. Fuller.** 1959. Ribulose 1,5-diphosphate carboxylase activity in relation to photosynthesis by intact leaves and isolated chloroplasts. Pl. Physiol. **34:** 651–656.

Stalfelt, M. G. 1955. The stomata as a hydrophotic regulator of the water deficit of the plant. Physiol. Plant. **8:** 572–593.

Stanier, R. Y. 1961. Photosynthetic mechanisms in bacteria and plants: development of a unitary concept. Bacteriol. Reviews **25:** 1–17.

———— **M. Doudoroff, R. Kunisawa, and E. Contopoulou.** 1959. The role of organic substrates in bacterial photosynthesis. Proc. Nat. Acad. Sci. (U. S.) **45:** 1246–1260.

Stern, B. K. and **B. Vennesland.** 1960. The carbon dioxide requirement for the photoevolution of oxygen by chloroplast preparations. Jour. Biol. Chem. **235:** PC51–PC53.

Strehler, B. L. 1953. Firefly luminescence in the study of energy transfer mechanisms. II. Adenosine triphosphate and photosynthesis. Arch. Biochem. and Biophys. **43**: 67–79.

Thimann, K. V. 1938. Absorption of carbon dioxide in photosynthesis. Science **88**: 506–507.

Thomas, J. B., and **A. M. J. Haans.** 1955. Photosynthetic activity of fragments of *Spirogyra* chloroplasts. Biochem. Biophys. Acta **18**: 286–288.

Tolmach, L. J. 1951. Effects of triphosphopyridine nucleotide upon oxygen evolution and carbon dioxide fixation by illuminated chloroplasts. Nature **167**: 946–948.

Trebst, A. V., M. Losada, and **D. I. Arnon.** 1960. Photosynthesis by isolated chloroplasts. XII. Inhibitors of CO_2 assimilation in a reconstituted chloroplast system. Jour. Biol. Chem. **235**: 840–844.

————, **H. Y. Tsujimoto,** and **D. I. Arnon.** 1958. Separation of light and dark phases in the photosynthesis of isolated chloroplasts. Nature **182**: 351–355.

Trudinger, P. A. 1956. Fixation of carbon dioxide by extracts of the strict autotroph *Thiobacillus dentrificans*. Biochem. Jour. **64**: 274–286

Umbreit, W. 1960. Sulfur (and selenium) bacteria. *In: Handbuch der Pflanzenphysiologie*, Vol. V, part 2, pp. 682–685, W. Ruhland, Ed., Springer, Heidelberg.

Van Niel, C. B. 1931. On the morphology and physiology of the purple and green sulphur bacteria. Arch. Microbiol. **3**: 1–112.

————. 1949. The comparative biochemistry of photosynthesis. *In: Photosynthesis in Plants*. J. Franck and W. E. Loomis, Eds., pp. 437–495, Iowa State College Press, Ames.

Vernon, L. P. and **O. K. Ash.** 1959. The photoreduction of pyridine nucleotides by chromatophores of *Rhodospirillum rubrum* in the presence of succinate. Jour. Biol. Chem. **234**: 1878–1882.

————, and **M. D. Kamen.** 1954. Studies on the metabolism of photosynthetic bacteria. XVII. Comparative studies on simultaneous photooxidations in bacterial and plant extracts. Arch Biochem. Biophys. **51**: 122–133.

————, and **W. S. Zaugg.** 1960. Photoreductions by fresh and aged chlorplasts: requirements for ascorbate and 2,6-dichlorophenoindophenol with aged chloroplasts. Jour. Biol. Chem. **235**: 2728–2733.

Vishniac, W., and **S. Ochoa.** 1951. Photochemical reduction of pyridine nucleotides by spinach grana and coupled carbon dioxide fixation. Nature **167**: 768–769.

————, and ————. 1952. Phosphorylation coupled to photochemical reduction of pyridine nucleotides by chloroplast preparations. Jour. Biol. Chem. **198**: 501–506.

————, **B. L. Horecker,** and **S. Ochoa.** 1957. Enzymic aspects of photosynthesis. Adv. in Enzymol. **19**: 1–77.

Warburg, O., G. Krippahl, H. S. Gewitz and **W. Völker.** 1959. Ueber den chemischen Mechanismus der Photosynthese. Zeitsch. Naturf. **14b**: 712–724.

————, ————, and **W. Schroeder.** 1955. Wirkungsspektrum eines Photosynthese-Ferments. Zeitsch. Naturf. **10b**: 631–639.

Weissbach, A., B. L. Horecker, and **J. Hurwitz.** 1956. The enzymatic formation of phosphoglyceric acid from ribulose diphosphate and carbon dioxide. Jour. Biol. Chem. **218**: 795–810.

Wessels, J. S. C. 1957. Studies on photosynthetic phosphorylation: I. Photosynthetic phosphorylation under anaerobic conditions. Biochem. Biophys. Acta **25**: 97–100.

————. 1958. Studies on photosynthetic phosphorylation. II. Photosynthetic phosphorylation under aerobic conditions. Biochim. Biophys. Acta **29**: 113–123.

Whatley, F. R., M. B. Allen, and **D. I. Arnon.** 1955. Photosynthetic phosphorylation as an anaerobic process. Biochim. Biophys. Acta **16:** 605–606.

————, ————, **L. L. Rosenberg, J. B. Capindale** and **D. I. Arnon.** 1956. Photosynthesis by isolated chloroplasts. V. Phosphorylation and carbon dioxide fixation by broken chloroplasts. Biochim. Biophys. Acta **20:** 462–468.

————, ————, **A. V. Trebst,** and **D. I. Arnon.** 1960. Photosynthesis by isolated chloroplasts. IX. Photosynthetic phosphorylation and CO_2 assimilation in different species. Pl. Physiol. **35:** 188–193.

Williams, A. M. 1956. Light-induced uptake of inorganic phosphate in cell-free extracts of obligately anaerobic photosynthetic bacteria. Biochim. Biophys. Acta **19:** 570.

Winogradsky, S. 1887. Ueber Schewefelbacterien. Bot. Zeit. **45:** 489–507, 513–523, 529–539, 545–559, 569–576, 585–594, 606–610.

————. 1888. *Zur Morphologie und Physiologie der Schwefelbacterien.* Arthur Felix, Leipzig.

————. 1904. Die Nitrifikation. *In: Handbuch der Technischen Mykologie.* F. Lafar, Ed., Second Edition, Vol. III, pp. 132–181. Gustav Fischer, Jena.

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BULLETIN OF THE TORREY BOTANICAL CLUB

VOL. 88, NO. 4, pp. 261–269 JULY, 1961

TORREYA

Report of the Chairman of the Field Committee of The Torrey Botanical Club for the Year 1960

The year 1960 witnessed further general improvement in attendance and in the participation of younger people and of graduate students in botany. The cooperation of the leaders was splendid. The field program was brought to the attention of biology classes and other departments interested in the natural sciences in schools. Also, a notice of the program appeared in *The New York Times*.

The illustration on the cover of the 1960 field booklet was sketched by Mr. Charles Clare, artist of the New York Botanical Garden. It depicts two distinct species of weedy *Cynanchum* that have been confused as one and the same in the Torrey area. As we have ascertained, they are easily told apart when in flower and the illustration shows the floral differences.

Our fondest hope is that the field program will inspire lasting botanical contributions, particularly as a result of observations carried out in the field. Very preliminary steps have been taken to interest members in a revision of Norman Taylor's *Flora of the Vicinity of New York*. This substantial project would necessitate the cooperation of a number of people for a considerable period of time. As things now stand, Mr. J. Harry Lehr is keeping a record of the more recent botanical literature bearing on the local area. Mr. Lehr might be interested in treating the genus *Carex* for the proposed revision, while Robert Meyer would possibly handle the *Gramineae* and Karl L. Brooks the fern allies. County records for some parts of the Torrey range are being assembled. Mr. Brooks has volunteered to help prepare the manuscript—should one eventually be at hand!

An addition has been made to the roster of officers for the field program in the designation of Co-Chairman to aid in the preparation of the field schedule and to substitute for the Chairman should occasion require it. The Co-Chairman of the Field Committee is Mr. Mulford Martin. Mr. Martin is presently working on the bryophytes in the Cryptogamic Herbarium of the New York Botanical Garden.—JOSEPH MONACHINO, The New York Botanical Garden.

FIELD TRIP REPORT

March 26. St. John's in the Wilderness, Sloatsburg, New York. The group hiked to Breakneck Pond before attending the annual service (see Bull. Torrey Bot. Club **81**: 460, 1954; **82**: 397, 1955; **83**: 385, 1956; **84**: 318, 1957; **85**: 273, 1958; **86**: 348, 1959; **87**: 283, 1960) but with five inches of snow on the trails, botanical activity was severely limited and ornithologically, the only item of interest was a small flock of migrating rusty blackbirds (*Euphagus carolinus*). Attendance: Torrey 4, Rockland-Audubon 10. Leader J. Harry Lehr.

LOCAL FLORA NOTES

Another "native" is now being used in increasing quantities by the cut flower trade in the New York City area. It is *Lycopodium cernuum* var. *crassifolium*, a native of Hawaii and other tropical regions. Although it is reported to be the most common species in Hawaii, from where it is being shipped, it is always debatable how long a native will remain common, once commercial people find a use for it.

* * * * * *

In a continuing investigation concerning floras of the local range written since the publication of Taylor's Flora of the Vicinity of New York in 1915, the following can be added to a growing list.

In April 1958 the New York State Museum published Bulletin 360 titled "Flora of the Columbia County Area, New York." It was written by Rogers McVaugh, but it is a

compendium of Dr. McVaugh's field work from 1930 until 1936; the late Dr. House' continued excursions into the area until 1949, and a complete revision of the nomenclature by Mr. Stanley J. Smith in 1955 in order that the completed work would conform with Fernald's new manual of the range. A little less than half of the volume is devoted to keys and an annotated list. The balance of the work is devoted to the history, geology, and ecology of the area with the emphasis on a detailed consideration of the associations. The writer of these notes regrets that three or four field trips into the area does not qualify him to present a critical review of this study, but a careful reading of it by him leaves the impression of thoroughness.

In 1943, Dr. Paul R. Wagner, now of Ursinus College, privately published a "Flora of Schuylkill County, Pennsylvania". It contains a brief discussion of the geography, geology, and the floral components of the area but the greater part of the volume is devoted to keys and an annotated check-list.

It should be remarked that neither of the two foregoing publications contain an index.

Among the list of local floras of the Torrey Club Range contained in Taylor's Flora of the Vicinity of New York was Conn. Geol. Nat. Hist. Surv. Bull. No. 14 titled "Catalogue of the Flowering Plants and Ferns of Connecticut Growing Without Cultivation". It was published in 1910. In 1930, Bull. No. 48 titled "Additions to the Flora of Connecticut" was published by the same committee. Although a few local floras have been published since, the 1930 bulletin is the last publication on the flora of the State as a whole.

Incidentally, the 1961 report of the Connecticut Botanical Society records a specimen of *Cornus rugosa* 18 feet tall growing in Naugatuck State Forest. The size of this shrub is double the maximum size reported in Fernald's new manual and in Gleason's new Britton & Brown. It was growing at the base of a talus slope where soil moisture seemed well-supplied but with good drainage. "Specimens growing in the crevices did not attain the size on this one specimen."—J. HARRY LEHR.

* * * * * *

Announcement. The herbaria of the New York Botanical Garden as a result of extensive renovation of the Museum Building housing the herbaria have been closed since June of 1960. Although initial schedules pre-supposed the completion of the renovation operations within 120 days, it remains unlikely that the Garden's herbarium collections will be accessible to either Garden staff or visitors until July of this year, or later.

During the period of the herbaria closure, more than a hundred requests for loans of herbarium material have been received at the Garden. That the specimens of a considerable number of these requests may no longer be needed is suggested by the cancellation of quite a few earlier made applications for loans.

In view of the probability that the need of many of the still outstanding requests has expired, we request all of our correspondents to submit a renewal of requests for loans, to become effective in July—or as soon thereafter as conditions permit. We hope that our colleagues throughout the world will be understanding of this interruption in the normal course of collaboration.—BASSETT MAGUIRE, Head Curator, New York Botanical Garden.

BOOK REVIEWS

Studies in Paleobotany. By Henry N. Andrews, Jr. xii + 487 pages. Illustrated and indexed. John Wiley and Sons, Inc., New York and London. $11.75.

In this welcome new textbook the approach to the study of fossil plants is "primarily a botanical one . . . concerned with the kinds of plants that have existed in the past for their own sake and for what they can tell us about the origins of modern floras." The book is well written, very adequately illustrated, and carefully documented.

The introduction presents the necessary geological and botanical background, in-

cluding a slightly modified version of Bold's system of plant classification, which is followed throughout the text. A short section on wood anatomy sets the tone for the book's over-all emphasis on internal structure.

The six chapters that follow describe "a broad stream of evolution, with many specialized side branches, beginning in the psilophyte complex and continuing through the 'preferns' in the Middle and Upper Devonian to true ferns and seed-ferns in the Carboniferous; and in turn the seed-ferns . . . [as] . . . the most likely source of the flowering plants." As an ardent advocate of a polyphyletic outlook, Andrews next presents separate chapters on the lycopodophytes and the arthrophytes, which are regarded as distinctly separate lines as far back as they can be recognized. The same view is held with regard to the cycadophytes, which are next treated as two independent groups, the extinct bennettites of the Mesozoic and the longer lived cycads. The following chapter discusses both the combined cordaite-conifer line, chiefly of the Late Paleozoic, as well as the more widely ranging ginkgophytes.

The rest of the book presents a miscellany of subjects which include: fossil mosses and liverworts; gymnospermous plants of uncertain affinities; heterospory and the evolution of the seed; fossil plants of the Arctic and Antarctic; some Paleozoic and Mesozoic floras; techniques for studying fossil plants; and a chapter on palynology, contributed by Charles J. Felix.

There are well selected and up-to-date references at the close of each chapter.

In line with the author's interests the emphasis throughout the book is on the evolution of plants as separate groups rather than on plants as separate floras. Within this framework much more attention is given to the lower than to the higher groups of plants. This results in the somewhat disproportionate concern with late Paleozoic—especially Carboniferous—groups at the expense of the Mesozoic and Cenozoic conifers (less than a page of text) and angiosperms (two chapters plus incidental mention elsewhere).

Andrews seems definitely to be impressed by the "tantalizing bits of evidence that vascular plants existed as far back as the Cambrian and perhaps in late pre-Cambrian times." He accepts as a reasonable explanation for their scarcity as fossils the theory that they lived in the uplands, where their record would be poor or destroyed by erosion. The exceptional and highly significant *Aldanophyton*, of Cambrian age, is regarded as possibly a land vascular plant, although proof of the presence of vascular tissue is completely lacking, as has been pointed out by Wilson N. Stewart and others during the past two years.

In his discussion of early angiosperms the author makes a stronger case than seems warranted of the scanty pre-Cretaceous records of supposed angiosperms; here again their preference for the uplands accounts for their poor fossil record. The other side of this important issue was critically and ably presented by Scott, Barghoorn, and Leopold in 1960 and further by Hughes in early 1961.

This book is an excellent addition to both botanical and paleobotanical literature.—ERLING DORF, Princeton University, Princeton, N. J.

Mushrooms of the Great Smokies, By L. R. Hesler. The University of Tennessee Press, Knoxville, Tennessee.

It is fitting that the first extensive popular book on mushrooms and related fungi to be written on one of our National Parks should be concerned with the Great Smoky Mountains National Park in Tennessee and North Carolina. For it is in this Park, more than any other, that the vegetation as represented by all groups of plants is sufficiently varied to hold the interest of both professional and amateur botanists for extended periods of time. Professor Hesler's interest in the area dates from his arrival at the University of Tennessee until the present. His explorations in the Park have been so extensive that for most habitats he can tell you in advance, on which side of a rock, a tree or a ravine you will find a given species, as well as the approximate date to look for it. Anyone who wishes to study the diversity of the flora of the Park should arm himself with a copy of "Mushrooms of the Great Smokies" and go hunting. Not all the fungi he finds will be in Hesler's book, because the fungous flora of the Park is exceed-

ingly large and varied, but a large number of the common things are included, and this is all that can be asked of a book within the price range ($5.50) of this one. The outstanding feature, of course, is the large number of good illustrations, as half tones, which cover the more conspicuous fungi regardless of group. Among the exceptionally fine ones are those of *Cronartium quercuum*, *Coprinus micaceus*, *Leptonia subserrulata*, *Marasmius siccus* (one of the most difficult fungi to photograph), *Cantharellus purpurascens* and *Urnula craterium*. Professional "agaricologists" and amateurs alike will want the book for these illustrations, and amateurs will find that it will be very useful as a field guide to the edible and poisonous fungi of the area. The write-ups accompanying each species are designed for use in the field and were not intended to be scientifically complete. Complete descriptions will be included in Professor Hesler's "Mushroom Flora of the Southeastern United States", which we hope will be published before too many years. In short, this book should add much pleasure to those interested in studying the Natural History of the Great Smokies, and in doing this play an important role in helping young and old together find new interests and experience the joy of exploration and discovery.—ALEXANDER H. SMITH.

A Study of Russula Types. By L. R. Hesler. Mem. Torrey Bot. Club 21 (2): 1–59. 1960.

One of the features that is rapidly coming to light as a result of microscopic studies of the types of higher fleshy fungi is that type material is apparently not as homogeneous, species wise, as one would expect it to be. Consequently it is highly desirable that type studies be made and carried to a degree of completion which will "fix" the concept of the species on a modern basis. Hesler's work on Russula is thus a step in the right direction and one which will aid materially in our arriving at more accurate and usable species concepts in a genus where these have been lacking in spite of its being studied more than almost any other genus of gill fungus.

There will undoubtedly be some differences of opinion in regard to the data presented in the paper, just as there have been differences of opinion on type studies in other genera, *Pluteus*, for example, but the differences serve both ways in that they indicate areas of agreement by inference if not by direct statement, and the points of disagreement will be the focus for future studies. Hesler is to be congratulated on placing more emphasis on the cutis of the pileus than has been done in some type studies, since it is in the dermal layers that significant differences are found in many groups of Agaricales. The drawings of the spores are excellently presented and show important differences in shape as well as ornamentation. The fine ornamentation of this type of spore, however, is likely to "vary" depending on the efficacy of the optical equipment used. This should be kept in mind by those making comparisons with his plates. The best solution to this problem, of course, would be studies involving the use of the electron microscope. Such studies, eventually, must be made.—ALEXANDER H. SMITH.

A Monograph of the Fontinalaceæ. By Winona M. Welch. vii + 367 pp. Martinus Nijhoff, The Hague, 1960, $10.

This monograph on the Fontinalaceae authoritatively limits this family of aquatic mosses by defining the genera and species to be included. In 1943 the author published a paper removing the genera *Wardia*, *Hydropogon* and *Hydropogonella* from the family on the basis of the absence of natural affinities between them and the remaining genera. According to the author's judgment, only the genera *Fontinalis*, *Dichelyma* and *Brachelyma* should be included in this family. She then defines briefly the diagnostic characteristics to be used to delimit the family.

Since the species in this family of mosses are subject to great variation due to the differing environmental conditions under which they grow, the characteristics used to separate species and genera are difficult to define. The terms applied to these diagnostic characteristics are carefully defined in the first chapter. The very definite procedure in

preparing specimens for examination, the parts of the plants that must be used and the type of measurments needed are carefully outlined. These directions are so explicit that almost any one using the monograph can satisfactorily place a specimen into its proper species or variety.

A detailed description of the family is followed by a key to the genera. Keys are also provided for the determination of species and varieties in each genus.

Under each species and variety description, Dr. Welch lists the synonymy for each species and variety and also includes a detailed description of the morphology with very clear and useful text figures. Since leaf form and structure is very important in separating the species, excellent figures of the leaves and leaf arrangement are included. The author indicates or designates the type, type collector when known, and the type locality. The geographic distribution of the species or variety is given, followed by a listing of all specimens examined and the herbaria in which they are deposited. The vast amount of precise work and care that has gone into the preparation of this monograph can be judged by the enormous number of specimens examined. At the end of each of the sections treating the individual species or variety, the specific differences between it and those species or varieties with which it might be confused are briefly summarized.

A chapter on fossil species is included. Excluded and uncertain species are listed. Exsiccati cited are listed together with the number and species. The distribution of species in the world by countries is summarized. A bibliography of the literature on the family is included and finally an index of collections cited is given under the names of the individual collectors.

It is a pleasure to be able to welcome this valuable addition to Bryological literature. This excellent monograph is the result of years of devotion and study of a very variable and difficult group of mosses. I cannot emphasize enough the careful research that has gone into its completion.—EDWIN T. MOUL, Botany Dept. Rutgers University.

Drawings of British Plants. Part XV. Compositae (1). By Stella Ross-Craig. *pl. 1–28*, index. London: G. Bell & Sons, Ltd. 23 Nov 1960. 9/6 [$1.33].

This latest part of the series introduces the Compositae (it should be borne in mind that these do not come at the end of the Bentham and Hooker system used in England). Twenty-seven species are beautifully illustrated in these 28 plates. Of these North American botanists will be interested in the circumpolar *Gnaphalium uliginosum; Erigeron canadensis* and *Bidens cernua*, contributed by us to British weeds; *Galinsoga parviflora* and *G. ciliata*, a contribution to both hemispheres from the American tropics; *Inula helenium* and *Bellis perennis*, which occasionally escape from cultivation here.—H. W. RICKETT.

Die Amarantaceen Mitteleuropas. By Paul Aellen. (Separately issued from G. Hegi, *Illustrierte Flora von Mitteleuropa*, 3 (2) : 461–535. *Col. pl. 95*) 1961. Carl Hanser, München. 20 DM (ca. $5.00).

Publication of the second edition of Hegi's well-known *Flora* continues with Volume 3 parts 1 and 2 and Volume 6 part 1. We have recently received the part here noticed, separately issued without change of pagination but provided with printed paper cover, title pages, preface, etc. The revision differs from the first edition chiefly by the inclusion of many taxa introduced from other parts of the world. Several new minor taxa are described.—H. W. RICKETT.

Flowers and Botanical Subjects on Stamps, Including Fruits, Trees, Vegetables, Seeds, Ferns, Etc. All Forms of Plant Life on Stamps. By Shirley C. Tucker and Claude Weber, edited by Sidney R. Esten. Index by

Merida Wilde. Bibliography by John Henry Richter. Photography by Gayle Foster. Topical Handbook No. 30, pp. 3-[163]. American Topical Association, 3300 North 50th Street, Milwaukee 16, Wisconsin. 1960. $6.00.

Philatelic botany, the collection and study of stamps bearing some form of plant life in their design, is an unusual and little known hobby. Many of its enthusiasts have joined with collectors of other topics—animals, athletics, works of art, medicine, modes of transportation, and others—in the American Topical Association. The 5,000 members of this international, non-profit organization are interested in the specific aspects of stamp design, rather than in the country of issue or the service purchased by the stamp. The Association publishes a bimonthly journal, Topical Time, and occasional Handbooks which cover specific topics.

The present handbook is one of the most unsual sources of specialized information on plants ever published. The primary section of this handbook is a 108 page checklist of stamps on which some form of plant life is pictured. These stamps are listed according to the family to which the plant on them belongs, except that 27 with algae are listed without subdivision and 23 with fungi are listed by classes. Within each of the families, which are arranged alphabetically within the major groups of ferns, gymnosperms, and angiosperms, the stamps are listed alphabetically by the scientific name of the plants depicted on them. Stamps on which two or more species are illustrated are listed for each of the species. There is a brief, popular description of each family in which economically important species and curiosities are mentioned.

The entry for each stamp contains the name of the country of issue, Scott number and type designations, year of issuance, denomination, the common and scientific names of the plant (when determinable), and a series of code letters which indicate the plant part illustrated, its position on the stamp; and whether or not the illustration is stylized.

Black and white illustrations of 191 stamps are scattered throughout the text. The value of these illustrations is lessened by several unfortunate circumstances. The illustrations are not arranged to correspond with the arrangement of the checklist, nor is there any reference in the checklist to the fact that a particular stamp is illustrated. In most of the illustrations, several stamps are grouped together on the basis of country of origin (p. 35), part of the design in which plants are utilized (p. 27), economic plants (p. 51), genus in common (p. 131), and in other ways. However, without a list of illustrations, one is forced to leaf through the pages to appreciate the logic of the groupings. It is also difficult to refer from the illustrations to the primary checklist to obtain details about a particular stamp. The scientific name and country of issue are given in the legend, but if one does not know the family name, he must consult the national index to learn the family before using the primary checklist. A further difficulty may be experienced, for one scientific name may be used in the legend of the illustration and a synonym of that name in the national index and primary checklist (e.g., *Carnegia gigantea* in legend on page 35, *Cereus gigantea* in the index and checklist.)

The second section, 35 pages in length, is a national index to plants illustrated on stamps. In this index, the common and generic names of the plants are listed for each country and the reader is referred to the proper family in the primary section of the handbook for individual stamp entries.

"A bibliography of philatelic botany," which occupies 15 pages, is a varied listing of general reference works, periodical indexes and abstracts, botanical textbooks and manuals, local floras, botanical journals, and books and articles on biological philately. The last are drawn entirely from 10 philatelic journals and do attempt to list articles on philatelic botany published in biological journals (as B. B. Thomas, 1954, Postage stamps tell forest industries importance. Unasylva, vol. 8, pp. 55–58). The utility of the bibliography is enhanced by an index to the scientific and common plant names prominently mentioned in the various entries. Many entries are accompanied by annotations, but some of these are overly "cute" or erroneous. For example, the reprint of Harshberger's "Phytogeographic survey of North America" is said to be an "Engl. edition of a German work . . ."

The handbook ends with a single page index to the English family names used in the primary section, combined with a general index to sectional headings. Several entries are without page references.

The handbook is well-printed on a heavy, coated paper, but its design is very unattractive. The covers are of relatively flexible, but durable Supertuff. A spiral plastic binding permits the book to be opened flat at any page, but the spine bears no title and is not easily labeled with call numbers which are so helpful when a book is shelved. A few typographical errors were noted, but these are minor and do not detract from the usefulness of the book.—JACK MCCORMICK, The American Museum of Natural History, New York, New York.

State Trees. By Olive L. Earle. Unpaginated [63 pp.], illus. William Morrow & Company, New York, 1960. $2.75.

Conservation teachers of primary and secondary grades as well as nature enthusiasts should find Miss Earle's tree book interesting reading. The index, which also serves as a table of contents, is arranged alphabetically by states with their corresponding state trees. In all, 34 different species are described. The difference between this number and the 50 states of the Union results from several states claiming identical species and others not as yet recognizing an "official" state tree.

Each species is adequately illustrated by Miss Earle's careful line drawings which are technically accurate but for a few minor errors. Examples of these are: persistent fascicular sheaths of the foliage of *Pinus monticola* (#25) and *P. strobus* (#24); the terminal bud of *P. palustris* (#20) in the "grass" stage is shown about twelve inches above ground line (it should be nested in the center of the fascicle sheaths close to the soil); and two-year old acorns on one-year old twigs of *Quercus rubra* (#14).

The text is presented in an interesting popularized style. It includes bits of natural history, general and morphologic descriptions as well as uses and silvical narrations. There are a few text errors, e.g. ". . . this pine [*Pinus echinata*] has the ability, unique among pines, to sprout new growth from its root," but it is known that *P. rigida* Mill., *P. taeda* L., *P. leiophylla* var. *chihuahuana* (Engelm.) Shaw, and others as well as *P. echinata* sprout from dormant buds at the root collar and not from the "root." Another example is "Popular" (Index) for Poplar. A few dimensions are also in error for "The whole leaf [*of Carya illinoensis*] is twelve to eighteen inches long—the largest leaf found on any member of the hickory clan . . ." contradicts a known length of *C. laciniosa* (Michx. f.) Loud. leaves of up to 22 inches. And Miss Earle claims that *Quercus rubra* is ". . . the largest of the red-oak group." but *Q. shumardii* Buckl. exceeds it both in maximum height and diameter.

Unfortunately Miss Earle only uses common names of the species she describes (no source of citation is given). The omission of Latin binomials leads to confusion by readers in various geographic areas of the Nation. A Californian knows *Quercus garryana* Dougl. as "white oak," but "white oak" is also illustrated by Miss Earle as the state tree of Maryland and Connecticut.

This review of "State trees" also presents the opportunity to correct and bring up-to-date her list of official and unofficial state trees. This compilation is shown in Fig. 1. Nomenclature for Earle and the 1961 survey except for *Aleurites moluccana* is from Little, E. L., Jr. 1953. "Check list of native and naturalized trees of the United States (including Alaska)." U. S. Dept. Agri., Agri. Hdbk. No. 41. 472 pp. Latin binomial equivalents of the trees discussed by Earle, the species found in the 1959 list of "State trees" (K-19, 4 pp.) by the United States Forest Service, and a list of trees compiled by my corresponding with state forestry officials or other competent botanical authorities of the states concerned are included in Fig. 1. Variations in nomenclature are shown and the current list reveals that several states now acknowledge official trees that are not included in the other two lists. Notable for the "new" trees are *Quercus coccinea* for the District of Columbia and *Aleurites moluccana* for Hawaii.

In summary Miss Earle's book is well written and illustrated and except for the few minor discrepancies should be of value to its readers. If additional and more technical information is desired, the reader should consult a standard dendrology text as Harlow, W. M. and E. S. Harrar. 1958. "Textbook of dendrology." Fourth ed. McGraw-Hill Book Co. Inc., New York. 561 pp.—JOHN ANDRESEN, Michigan State University.

Figure 1. Compilation of state trees listed by Earle (1960), the U. S. F. S. (1959), and by state forestry officials in reply to 1961 survey.

State	Earle	U. S. F. S.	1961 Survey
Alabama	*Pinus palustris* Mill.	*Pinus* spp.	–*
Alaska	None	–	–(Legislation pending)
Arizona	*Cercidium* spp.	–	–
Arkansas	*Pinus echinata* Mill.	*Pinus spp.*	*Pinus echinata*
California	*Sequoia* spp.	–	–
Colorado	*Picea pungens* Engelm.	–(Unofficial)	–
Connecticut	*Quercus alba* L.	–	–
Delaware	*Ilex opaca* Ait.	–	–
District of Columbia	None	–	*Quercus coccinea* Muenchh.
Florida	*Sabal palmetto* (Walt.) Lodd.	–	–
Georgia	*Quercus virginiana* Mill.	–	–
Hawaii	*Cocos nucifera* L.	–	*Aleurites moluccana* Willd.
Idaho	*Pinus monticola* Dougl.	–	–
Illinois	*Quercus* spp.	–	*Quercus macrocarpa* Michx.
Indiana	*Liriodendron tulipifera* L.	–	–
Iowa	None	–	–
Kansas	*Populus* spp.	–	*Populus deltoides* Bartr.
Kentucky	*Liriodendron tulipifera* L.	–	–
Louisiana	None	*Magnolia grandiflora* L. (Unofficial)	–
Maine	*Pinus strobus* L.	–	–
Maryland	*Quercus alba* L.	–	–
Massachusettes	*Ulmus americana* L.	–	–
Michigan	*Pinus strobus* L.	–	–
Minnesota	*Pinus resinosa* Ait.	–	–
Mississippi	*Magnolia grandiflora* L.	–	–
Missouri	*Cornus florida* L.	–	–
Montana	*Pinus ponderosa* Laws.	–	–
Nebraska	*Ulmus americana* L.	–(Unofficial)	–
Nevada	*Pinus monophylla* Torr. and Frem.	–	–
New Hampshire	*Betula papyrifera* Marsh.	–	–
New Jersey	*Quercus rubra* L.	–	–
New Mexico	*Pinus edulis* Engelm.	–	–
New York	*Acer saccharum* Marsh.	–	–
North Carolina	None	–	–
North Dakota	*Ulmus americana* L.	–	–
Ohio	*Aesculus glabra* Willd.	–	–
Oklahoma	*Cercis canadensis* L.	–	–
Oregon	*Pseudotsuga menziesii* (Mirb.) Franco	*Pseudotsuga taxifolia* (Poir.) Britton (name given in law)	*Pseudotusga menziesii*

Pennsylvania	*Tsuga canadensis* (L.) Carr	–	–
Rhode Island	*Acer rubrum* L.	*Acer* spp. (Unofficial)	*Acer rubrum* (Unofficial)
South Carolina	*Sabal palmetto* (Walt.) Lodd.	–	–
South Dakota	*Picea glauca* var. *glauca*	*Picea glauca* var. *densata* Bailey (name given in law)	*Picea glauca* var. *glauca*
Tennessee	*Liriodendron tulipifera* L.	–	–
Texas	*Carya illinoensis* (Wangenh.) K. Koch	–	–
Utah	*Picea pungens* Engelm.	–	–
Vermont	*Acer saccharum* Marsh.	–	–
Virginia	None	*Cornus florida* L. (Not Official)	–
Washington	*Tsuga heterophylla* (Raf.) Sarg.	–	–
West Virginia	*Acer saccharum* Marsh.	–	–
Wisconsin	*Acer saccharum* Marsh.	–	–
Wyoming	*Populus balsamifera* L.	–	*Populus sargentii* Dode (Legislative amendment pending)

*Dash indicates same nomenclature or species as in preceding column.

INDEX TO AMERICAN BOTANICAL LITERATURE

COMPILED BY

CLARK T. ROGERSON

WITH THE COLLABORATION OF

LAZELLA SCHWARTEN, H. W. RICKETT, AND HERMAN BECKER

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ALGAE

Abbott, Isabella A. On *Schimmelmannia* from California and Japan. Pacif. Nat. **2**: 379–386. 28 Apr 1961.

Burkholder, Paul R., Burkholder, Lillian M. & Almodovar, Luis R. Antibiotic activity of some marine algae of Puerto Rico. Bot. Marina **2**: 149–156. Oct 1960.

Clark, William J. & Sigler, William F. Preliminary investigation of the phytoplankton of Bear Lake, Utah-Idaho. Trans. Am. Micr. Soc. **80**: 28–32. Jan 1961.

Dawson, E. Yale. A new gigartinoid *Grateloupia* (red alga) from Hawaii. Pacif. Nat. **1**(1): 1–5. Dec 1958.

Dawson, E. Yale. Marine red algae of Pacific Mexico. Part 4. Gigartinales. Pacif. Nat. **2**: 191–343. 28 Apr 1961.

Dawson, E. Yale. New records of marine algae from Mexico and Central America. Pacif. Nat. **1**(20): 31–52. Jun 1960.

Dawson, E. Yale. Some algae from Clipperton Island and the Danger Islands. Pacif. Nat. **1**(7): 1–8. Jun 1959.

Dawson, E. Yale. William H. Harvey's report on the marine algae of the United States north Pacific Exploring Expedition of 1953–56 (edited). Pacif. Nat. 1(5): 1–40. Mai 1959.

Dawson, E. Yale & Beaudette, Palmer T. Field notes from the 1959 eastern Pacific Cruise of the Stella Polaris. Pacif. Nat. 1(13): 1–24. Nov 1959.

Dawson, E. Yale, Neushul, M. & Wildman, R. D. New records of sublittoral marine plants from Pacific Baja California. Pacif. Nat. 1(19): 1–30. Jun 1960

Dawson, E. Yale, Neushul, M. & Wildman, R. D. Seaweeds associated with kelp beds along southern California and northwestern Mexico. Pacif. Nat. 1(14): 1–81. Mar 1960.

Deason, Temd R. & Bold, Harold C. Phycological studies I. Exploratory studies of Texas soil algae. Univ. Texas Publ. 6022: 1–72. 15 Nov 1960.

Doty, Maxwell S. & Abbott, Isabella A. Studies in the Helminthocladiaceae (Rhodophyta): *Helminthocladia*. Pacif. Sci. 15: 56–63. Jan 1961.

Durrell, L. W. & Shields, Lora Mangum. Characteristics of soil algae relating to crust formation. Trans. Am. Micr. Soc. 80: 73–79. Jan 1961.

Fan, Kung-Chu. Morphological studies of the Gelidiales. Univ. Calif. Publ. Bot. 32: 315–368. 25 Jan 1961.

Hillis, Llewellya W. A revision of the genus *Halimeda* (order Siphonales). Inst. Marine Sci. 6: 321–403. 1959.

Hollenberg, G. J. *Smithora*, an interesting new algal genus in the Erythropeltidaceae. Pacif. Nat. 1(8): 1–12. Aug 1959.

Hollenberg, G. J. & Dawson, E. Yale. Marine red algae of Pacific Mexico. Part 5. The genus *Polysiphonia*. Pacif. Nat. 2: 345–375. 28 Apr 1961.

Koster, Joséphine Th. Caribbean brackish and freshwater Cyanophyceae. Blumea 10: 323–366. 1 Dec 1960.

Norris, Richard E. The structure and reproduction of *Glaphyrymenia pustulosa*. Am. Jour. Bot. 48: 262–268. Mar [28 Feb] 1961.

Parker, Bruce C., Bold, Harold C., & Deason, Temd R. Facultative heterotrophy in some chlorococcacean algae. Science 133: 761–763. 17 Mar 1961.

Patrick, Ruth & Freese, Leonard R. Diatoms (Bacillariophyceae) from northern Alaska. Proc. Acad. Phila. 112: 129–293. 1960 [24 Feb 1961].

Schumacher, George John. Biology of the Allegany Indian Reservation and vicinity. Part I: The algae. Bull. N. Y. St. Mus. 383: 5–18. Jan 1961.

Skottsberg, C. & Neushul, M. *Phyllogigas* and *Himantothallus*, antarctic Phaeophyceae. Bot. Marinas 2: 164–173. Oct 1960.

BRYOPHYTES

Andrews, A. LeRoy. Notes on North American *Sphagnum*. XII. *Sphagnum cyclophyllum*. Bryologist 63: 229–234. 1960 [28 Feb 1961].

Bartram, Edwin B. Northwestern Himalayan Mosses. II. Revue Bryol Lichénol. 29: 165–172. 1960.

Blomquist, H. L. "Fruiting" specimens of *Sphagnum portoricense*. Bryologist 63: 225–229. 1960 [28 Feb 1961].

Bonner, C. E. B. & Miller, H. A. Studies in Lejeuneaceae. I. The typification of *Lejeunea*. Bryologist 63: 217–225. 1960 [28 Feb 1961].

Engle, Mildred Joan. Corticolous bryophytes on *Pinus* in Florida. Bryologist 63: 238–241. 1960 [28 Feb 1961].

Herzog, Th. Weitere Beiträge zur Bryophytenflora von Chile. Revue Bryol. Lichénol. **29**: 183–206. 1960

Kachroo, P. & Schuster, R. M. The genus *Pycnolejeunea* and its affinities to *Cheilolejeunea, Euosmolejeunea, Nipponolejeunea, Tuyamaella, Siphonolejeunea* and *Strepsilejeunea*. Jour. Linn. Soc. Bot. **56**: 475–511. Feb 1961.

Kucyniak, James. Les Anthocérotées du Québec. Nat. Canad. **88**: 25–38. Feb 1961.

Lawton, Elva. *Pseudoscleropodium purum* in the Pacific Northwest. Bryologist **63**: 235–237. 1960 [28 Feb 1961].

Lersten, Nels R. A note on the sexual condition in *Mnium spinulosum*. Bryologist **63**: 245–246. 1960 [28 Feb 1961].

Redfern, Paul L. The bryophytic vegetation of exposed limestone at Pronto Springs, Florida. Revue Bryol. Lichénol. **29**: 235–243. 1960.

Robinson, Harold & Godfrey, R. K. Contribution to the bryophyte flora of Turkey. Revue Bryol. Lichénol. **29**: 244–253. 1960.

Sharma, Krishan Kanta, Diller, Violet M. & Fulford, Margaret. Studies on the growth of *Haplomitrium*. II. Media containing amino acids. Bryologist **63**: 203–212. 1960 [28 Feb 1961].

Ward, Max. Some techniques in the culture of mosses. Bryologist **63**: 213–217. 1960 [28 Feb 1961].

Weber, William A. A second American record for *Oreas martiana* from Colorado. Bryologist **63**: 241–244. 1960 [28 Feb 1961].

FUNGI

Amadjian, Vernon. The lichen association. Bryologist **63**: 250–254. 1960 [28 Feb. 1961].

Artagaveytia-Allende, R. C. Levaduras aisladas frente a las costas del Uruguay. Atti Ist. Bot. Pavia **18**: 1–4. 1960.

Barr, Margaret E. Northern pyrenomycetes. II. Gaspesian Park. Canad. Jour. Bot. **39**: 307–325. 20 Mar 1961.

Benjamin, C. R. & Hesseltine, C. W. Studies on the genus *Phycomyces*. Mycologia **51**: 751–771. 1959. [14 Apr 1961].

Berry, Charles R. Factors affecting parasitism of *Piptocephalis virginiana* on other Mucorales. Mycologia **51**: 824–832. 1959. [14 Apr 1961].

Bonner, R. D. & Fergus, C. L. The fungus flora of cattle feeds. Mycologia **51**: 855–863. 1959 [14 Apr 1961].

Bowerman, Constance A. *Lycoperdon* in eastern Canada with special reference to the Ottawa district. Canad. Jour. Bot. **39**: 353–383. *pl. 1, 2*. 20 Mar 1961.

Butler, E. E., Ogawa, J. M. & Shalla, T. Notes on *Gilbertella persicaria* from California. Bull. Torrey Club **87**: 397–401. 15 Dec 1960.

Chaves Batista, A., Jarbas Silveira, S. & Pessoa Coelho, R. *Debaryomyces artagaveytiae* n. sp. assinalado em secreção genital de mulher. Mycopath. Mycol. Appl. **14**: 19–23. 20 Feb 1961.

Chaves Batista, A., Américo de Lima, J. & Luiz Bezzera, J. Algunus novos fungos dos gêneros *Arthrobotryum, Atractina, Periconia* e *Podosporium*. Atti Ist. Bot. Pavia **18**: 160–167. 1960.

Chaves Batista, A. & Luiz Bezerra, J. Uma nova fumagina de *Sorghum halepense* (L.) Pers. Atti Ist. Bot. Pavia **18**: 168–170. 1960.

Christensen, C. M., Papavizas, G. C. & Benjamin, C. R. A new halophilic species of *Eurotium* [*halophilicum*]. Mycologia **51**: 636–640. 1959 [17 Mar 1961].

Ciferri, R., Chaves Batista, A. & Montemartini, A. Una capnodiacea imperfetta (Asbolisiacea) vivente sul legname in opera. Atti. Ist. Bot. Pavia **18**: 310–313. 1960.

Cooke, Wm. Bridge. Pollution effects on the fungus population of a stream. Ecology **42**: 1–18. Jan 1961.

Cooke, Wm. Bridge & Bonar, Lee. Additional fungi from the Galápagos and other Pacific coastal islands collected during the Templeton Crocker expedition, 1932. Occ. Pap. Calif. Acad. Sci. **29**: 1–5. 30 Jan 1961.

Cooke, Wm. Bridge & Nyland, George. Clathraceae in California. Madroño **16**: 33–42. 18 Apr 1961.

Culberson, William Louis. *Parmelia pseudoborreri* Asahina, lichen nouveau pour la flore d'Europe et remarques sur les "espèces chimiques" en lichénologie. Revue Bryol. Lichénol. **29**: 321–325. 1960.

Culberson, William L. The discovery of the lichen *Parmeliopsis placorodia* in western North America. Madroño **16**: 31. 20 Jan 1961.

Culberson, William L. The *Parmelia quercina* group in North America. Am. Jour. Bot. **48**: 168–174. Feb 1961.

Cummings, Jean M. Iodine as an aid in identification of asci and ascospores of *Schizosaccharomyces octosporus*. Stain Tech. **36**: 92, 93. Mar 1961.

Denison, William C. Some species of the genus *Scutellinia*. Mycologia **51**: 605–635. 1959 [17 Mar 1961].

Denton, J. Fred, McDonough, E. S., Ajello, Libero & Ausherman, Robert J. Isolation of *Blastomyces dermatitidis* from soil. Science **133**: 1126, 1127. 14 Apr 1961.

Drechsler, Charles. Several Zoopagaceae subsisting on a nematode and on some terricolous amoebae. Mycologia **51**: 787–823. 1959 [14 Apr 1961].

Edward, J. C. A new genus of the Moniliaceae [*Acrophialophora nainiana* gen. & sp. nov.]. Mycologia **51**: 781–786. 1959 [14 Apr 1961].

Frey, D. Isolation of a new species of *Aleurisma* [*keratinophilum*] from soil in in Australia and New Guinea. Mycologia **51**: 641–646. 1959 [17 Mar 1961].

Gilbertson, Robert L. Polyporaceae of the Western United States and Canada I. *Trametes* Fries. Northw. Sci. **35**: 1–20. Feb 1961.

Gray, William D. The laboratory cultivation of *Physarum flavicomum*. Am. Jour. Bot. **48**: 242, 243. Mar [28 Feb] 1961.

Groves, J. Walton & Elliott, Mary E. Self-fertility in the Sclerotiniaceae. Canad. Jour. Bot. **39**: 215–231. *pl. 1–3*. 25 Jan 1961.

Hammond, George H. Observations on infection of white grubs, *Phyllophaga* spp., by *Cordyceps ravenellii* Berk. & Curt. in eastern Canada. Canad. Field-Nat. **75**: 41, 42. 9 Mar 1961.

Hardison, J. R., Meiners, J. P., Hoffmann, J. A. & Waldher, J. T. Susceptibility of Gramineae to *Tilletia contraversa*. Mycologia **51**: 656–664. 1959 [17 Mar 1961].

Herre, Albert W. C. T. Notes on Chilean Usneas with description of one new species [*Usnea eyerdami*]. Revue Bryol. Lichénol. **29**: 274–276. 1960.

Hudson, H. J. *Heliscus submersus* sp. nov., an aquatic hyphomycete from Jamaica. Brit. Mycol. Soc. Trans. **44**: 91–94. *pl. 7*. Mar 1961.

Jenkins, S. F. & Winstead, N. N. Observations on the sexual stage of *Colletotrichum orbiculare*. Science **133**: 581, 582, 24 Feb 1961.

Johnson, G. T. The Trypetheliaceae of Mississippi. Mycologia **51**: 741–750. 1959 [14 Apr 1961].

Kaplan, William, Ajello, Libero, Di Bitetto, Daniel B. & McDonough, Eugene S. The discovery of *Histoplasma capsulatum* in Connecticut soil incidental to the investigation of a case of feline cryptococcosis. Mycopath. Mycol. Appl. **14**: 1–8. 20 Feb 1961.

Korf, Richard P. *Jafnea*, a new genus of the Pezizaceae. Nagaoa **7**: 3–8. *pl. 1.* Dec 1960.

Kuehn, Harold H. A preliminary survey of the Gymnoascaceae. II. Mycologia **51**: 665–692. 1959 [17 Mar 1961].

Kuehn, Harold H. & Orr, G. F. Observations on Gymnoascaceae. VI. A new species of *Arachniotus* [*flavoluteus*]. Mycologia **51**: 864–870. 1959 [14 Apr 1961].

Kukkonen, Ilkka. The smuts of the genus *Cintractia* parasit[iz]ing *Kobresia* species. Canad. Jour. Bot. **39**: 155–164. 25 Jan 1961.

Lloyd, C. G. A compilation of the Volvae of the United States. [1898, Reprinted]. Lloydia **23**: 118–142. Dec 1960 [10 Apr 1961].

Lowy, Bernard. New or noteworthy Tremellales from Bolivia. Mycologia **51**: 840–850. 1959 [14 Apr 1961].

Luedmann, George M. The dictyochlamydospore of *Peyronellaea glomerata* (Corda) Goidanich ex Togliani contrasted with the dictyoporospore of *Alternaria tenuis* Auct. Mycologia **51**: 772–780. 1959 [14 Apr 1961].

McManus, *Sister* M. Annunciata & Richmond, *Sister* M. Vianney. Spore to spore culture on agar of *Stemonitis fusca*. Am. Midl. Nat. **65**: 246. Jan 1961.

Martin, G. W. Taxonomic notes on Myxomycetes, III. Brittonia **13**: 109–113. 30 Jan 1961.

Miller, J. J. & Reid, James. Stimulation by light of sporulation in *Trichoderma lignorum* (Tode) Harz. Canad. Jour. Bot. **39**: 259–262. *pl. 1.* 20 Mar 1961.

Moore, Royall T. The genus *Berkleasmium*. Mycologia **51**: 734–739. 1959. [17 Mar 1961].

Moore, Royall T. & Meyers, Samuel P. Thalassiomycetes I. Principles of delimitation of the marine mycota with the description of a new aquatically adapted deuteromycete genus [*Nia vibrissa* gen. and sp. nov.]. Mycologia **51**: 871–876. 1959 [14 Apr 1961].

Olive, Lindsay S. & Fantini, A. A. A new, heterothallic species of *Sordaria* [*brevicollis* sp. nov.]. Am. Jour. Bot. **48**: 124–128. 15 Feb 1961.

Parmelee, John A. The fungi of Ontario. I. Uredinales. Canad. Dep. Agr. Res. Branch Publ. **1080**: 1–46. Apr 1960.

Petersen, R. H. A new species of *Mastigosporium* [*heterosporum*] from tropical soil. Mycologia **51**: 729–733. 1959 [17 Mar 1961].

Rodriguez, Jose D. Piedra en Ecuador. Mycopath. Mycol. Appl. **14**: 31–38. 20 Feb 1961.

Sarkar, Arati. Studies on the anthracnose fungus of *Hibiscus cannabinus* L. Lloydia **23**: 97–101. Dec 1960 [10 Apr 1961].

Schnathorst, W. C. Heterothallism in the lettuce strain of *Erysiphe cichoracearum*. Mycologia **51**: 708–711. 1959 [17 Mar 1961].

Snider, Philip J. Stages of development in rhizomorphic thalli of *Armillaria mellea*. Mycologia **51**: 693–707. 1959 [17 Mar 1961].

Snyder, William C. & Alexander, James V. Perfect stages of *Fusarium oxysporum* and of *Fusarium solani* f. *pisi* still unknown. Nature **189**: 596. 18 Feb 1961.

Solheim, W. G. Mycoflora saximontanensis exsiccata centum XII. Univ. Wyoming Publ. Sci. **24**: 34–55. 15 Jul 1960.

Solheim, W. G. & Cummins, George B. Mycoflora saximontanensis exsiccata centum XI. Univ. Wyoming Publ. Sci. **24**: 22–33. 15 Jul 1960.

Thind, K. S., Cash, Edith K. & Singh, Pritam. The Helotiales of the Mussoorie Hills—II. Mycologia **51**: 833–839. 1959 [14 Apr 1961].

Thompson, John W. *Agrestia cyphellata*, a new genus and species of lichen in the Usneaceae. Bryologist **63**: 246–250. 1960 [28 Feb 1961].

Turner, P. D. Complementary isolates of *Phytophthora palmivora* from cacao and rubber, and their taxonomy. Phytopathology **51**: 161–164. 15 Mar 1961.

Vogel, Henry J. Lysine synthesis and phylogeny of lower fungi: Some chytrids versus *Hyphochytrium*. Nature **189**: 1026, 1027. 25 Mar 1961.

Ward, E. W. B., Lebeau, J. B. & Cormack, M. W. Grouping of isolates of a low-temperature basidiomycete on the basis of cultural behavior and pathogenicity. Canad. Jour. Bot. **39**: 297–306. *pl. 1*. 20 Mar 1961.

Wasson, R. Gordon. The hallucinogenic fungi of Mexico; An inquiry into the origins of the religious idea among primitive peoples. Bot. Mus. Leafl. **19**: 137–162. 17 Feb 1961.

Welden, A. L. & Lemke, P. A. Distribution of some Mexican fungi in North America. Am. Midl. Nat. **65**: 111–117. Jan [Feb] 1961.

West, Erdman. *Sclerotium rolfsii*, history, taxonomy, host range, and distribution [Symposium on *Sclerotium rolfsii*]. Phytopathology **51**: 108, 109. 20 Feb 1961.

Wilson, James F. Micrurgical techniques for *Neurospora*. Am. Jour. Bot. **48**: 46–51. 23 Jan 1961.

PTERIDOPHYTES

Britton, Donald. The problems of variation in North American *Dryopteris*. Am. Fern Jour. **51**: 23–30. 20 Apr 1961.

Brownlie, G. Studies on Pacific ferns, part III. The lindsaeoid ferns. Pacif. Sci. **15**: 64–66. Jan 1961.

Champlin, Richard L. A fern new to Rhode Island [*Asplenium montanum*]. Rhodora **63**: 46. Feb [27 Mar] 1961.

Cody, W. J. New forms in *Botrychium virginianum*. Am. Fern. Jour. **51**: 36, 37. 20 Apr 1961.

Darling, Thomas. Florida rarities. Am. Fern Jour. **51**: 1–15. 20 Apr 1961.

Henry, L. K. & Buker, W. E. Recent fern discoveries in western Pennsylvania. Am. Fern. Jour. **51**: 42, 43. 20 Apr 1961.

Morton, C. V. Taxonomic notes on ferns, II. Am. Fern Jour. **51**: 37–42. 20 Apr 1961.

Proctor, George R. Notes on Lesser Antillean ferns. Rhodora **63**: 31–35. Feb [27 Mar] 1961.

Root, Elizabeth Eichstedt. Hybrids in North American Gymnocarpiums. Am. Fern Jour. **51**: 15–22. 20 Apr 1961.

Smith, Dale M., Bryant, Truman R. & Tate, Donald E. *Asplenium* × *gravesii* in Kentucky. Brittonia **13**: 69–72. 30 Jan 1961.

Tryon, Rolla. Taxonomic fern notes. I. Rhodora **63**: 70–88. *pl. 1255–1258*. 29 Mar 1961.

Wagner, W. H. Some new data on the vernation differences of *Botrychium dissectum* and B. *ternatum*. Am. Fern Jour. **51**: 31–33. 20 Apr 1961.

Wherry, Edgar T. Supplementary note on *Dryopteris* hybrids. Am. Fern Jour. **51**: 33–35. 20 Apr 1961.

SPERMATOPHYTES

Adams, William P. & Robson, Norman K. B. A re-evaluation of the generic status of *Ascyrum* and *Crookea* (Guttiferae). Rhodora **63**: 10–16. 26 Jan 1961.

Ahloowalia, B. S. & Garber, E. D. The genus *Collinsia*. XIII. Cytogenetic studies of interspecific hybrids involving species with pediceled flowers. Bot. Gaz. **122**: 219–228. Mar [11 Apr] 1961.

Alexander, E. J. *Ortegocactus*, a unique new genus [*O. macdougallii* sp. nov.]. Cact. Succ. Jour. **33**: 39, 40. Mar–Apr 1961.

Bean, R. C., Hill, A. F. & Eaton, R. J. Fourteenth report of the Committee on plant distribution. Rhodora **63**: 47–55. Feb [27 Mar] 1961.

Beetle, Alan A. Distribution as a key to the age and origin of grasses. Univ. Wyoming Publ. Sci. **24**: 1–8. 15 Jul 1960.

Bell, Sandra L. & Garber E. D. The genus *Collinsia*. XII. Cytogenetic studies of interspecific hybrids involving species with sessile flowers. Bot. Gaz. **122**: 210–218. Mar [11 Apr] 1961.

Benson, Lyman. A revision and amplification of *Pediocactus* I. Cact. Succ. Jour. **33**: 49–54. Mar–Apr 1961.

Bose, Smritimoy, & Janick, Jules. Karyo-races in *Spinacia oleracea*. Am. Jour. Bot. **48**: 238–241. Mar [28 Feb] 1961.

Bowden, Wray M. Chromosome numbers and taxonomic notes on northern grasses. III. Twenty-five genera. Canad. Jour. Bot. **38**: 541–557. Jul 1960. IV. Tribe Festuceae: *Poa* and *Puccinellia*. **39**: 123–138. 25 Jan 1961.

Breitung, August J. Cultivated and native agaves in the southwestern United States. 12. Cact. Succ. Jour. **33**: 22–24. Jan–Feb. 13. 35–38. Mar–Apr 1961.

Brizicky, George K. The genera of Turneraceae and Passifloraceae in the southeastern United States. Jour. Arnold Arb. **42**: 204–218. 15 Apr 1961.

Brown, J. R. Notes on Haworthias. Cact. Succ. Jour. **33**: 46–48. Mar–Apr 1961.

Chambers, Henrietta L. Chromosome numbers and breeding systems in *Pycnanthemum* (Labiatae). Brittonia **13**: 116–128. 30 Jan 1961.

Cowan, Richard S. Leguminosae [*in* Botany of the Guayana Highland—part IV (2)]. Mem. N. Y. Bot. Gard **10**(4): 65–87. 15 Mar 1961.

Cuatrecassas, José. A taxonomic revision of the Humiriaceae. Contr. U. S. Natl. Herb. **35**: 25–214. pl. *1–24*. 1961.

Degener, Otto & Degener, Isa. A new Hawaiian variety of *Capparis*. Phytologia **7**: 369. 11 Mar 1961.

Dress, William J. *Chlorophytum* (Liliaceae) in cultivation. Baileya **9**: 29–50. 31 Mar 1961.

Duke, James A. Chenopodiaceae, Amaranthaceae, Caryopyllaceae [*in* Flora of Panama, Part IV, Fascicle 4]. Ann. Missouri Bot. Gard. **48**: 1–50, 90–106. Feb [3 Apr] 1961.

Frankton, C. & Moore, R. J. Cytotaxonomy, phylogeny, and Canadian distribution of *Cirsium undulatum* and *Cirsium flodmanii*. Canad. Jour. Bot. **39**: 21–33. *pl. 1*. 25 Jan 1961.

Gillett, George W. An experimental study of variation in the *Phacelia sericea* complex. Am. Jour. Bot. **48**: 1–7. 23 Jan 1961.

Grant, William F. Speciation and basic chromosome number in the genus *Celosia*. Canad. Jour. Bot. **39**: 45–50. *pl. 1*. 25 Jan 1961.

Hall, Ivan V. & Aalders, Lewis E. Cytotaxonomy of lowbush blueberries in eastern Canada. Am. Jour. Bot. **48**: 199–201. Mar [28 Feb] 1961.

Hawkes, Alex D. As orquídes de Cuba. Orquídea Rio de Janeiro **22**: 174–179. Sep–Oct 1960 [1961].

Hawksworth, Frank G. Observations on *Arceuthobium vaginatum* in Mexico. Madroño **16**: 31, 32. 20 Jan 1961.

Hodgdon, A. R. & Pike, Radcliffe. An ecological interpretation of *Rhododendron* colonies in Maine and New Hampshire. Rhodora **63**: 61–70. 29 Mar 1961.

Hodgdon, A. R. & Pike, Radcliffe. *Rhododendron maximum* in Hopkinton and Harrisville, New Hampshire. Rhodora **63**: 26–29. 26 Jan 1961.

Hollister, Paul L. & Mitchell, Carrie L. A puzzle among the Compositae of the Eastern Highland Rim. Jour. Tenn. Acad. **36**: 71–76. Jan 1961.

Horich, Clarence K. *Wilmattea minutiflora*. Cact. Succ. Jour. **33**: 17–19. Jan–Feb 1961.

Howard, Richard A. Studies in the genus *Coccoloba*, X. New species and a summary of distribution in South America. Jour. Arnold Arb. **42**: 87–95. XI. Notes on the species of Asia. 107–109. Jan 1961.

Howard, Richard A. The botanical results of the U. S. Commission of inquiry to Santo Domingo in 1871. Jour. Arnold Arb. **42**: 115–143. 15 Apr 1961.

Hu, Shiu-ying. The economic botany of the Paulownias. Econ. Bot. **15**: 11–27. Jan–Mar [Apr] 1961.

Ingram, John. Studies in the cultivated Boraginaceae 4. A key to the genera. Baileya **9**: 1–12. 31 Mar 1961.

Keener, Carl S. A preliminary catalogue of the flora of Lebanon County, Pennsylvania. Bartonia **30**: 1–15. 13 Jan 1961.

Kimnach, Myron. *Disocactus ramulosus*. Cact. Succ. Jour. **33**: 11–16. Jan–Feb 1961.

Kobuski, Clarence E. Studies in the Theaceae, XXX. The African species of *Ternstroemia*. Jour. Arnold Arb. **42**: 81–86. XXXI. A new species of *Adinandra* [*eymae*] from the Celebes. 112, 113. Jan 1961.

Laughlin, Kendall. *Quercus discreta* Laughlin, Hibrida nova, *Quercus shumardii* × *velutina*. Phytologia **7**: 410–416. 11 Mar 1961.

Lebrun, J. Quelques remarques sur la flore et la végétation du Canada (Ontario Méridional—Québec, region de Montréal). Vegetatio **10**: 25–41. 31 Jan 1961.

Leinig, Milton. Contribuição à lista geral das orquídeas paranaenses—III. Orquídea Rio de Janeiro **22**: 134, 135. Jul–Aug 1960 [1961].

Leonard, Emery C. Acanthaceae [*in* Botany of the Guayana Highlands—part IV (2)]. Mem. N. Y. Bot. Gard. **10**(4): 47–58. 15 Mar 1961.

Lepage, Ernest. Études sur quelques plantes Américaines.—IX. Nat. Canad. **88**: 44–52. Feb 1961.

Leppik, E. E. Early evolution of flower types. Lloydia **23**: 72–92. Sep 1960 [8 Mar 1961].

Leppik, E. E. Evolutionary differentiation of the flower head of the Compositae. Arch. Soc. "Vanamo" **14**: 162–181. 1960.

Long, Robert W. Biosystematics of two perennial species of *Helianthus* (Compositae), II. Natural populations and taxonomy. Brittonia **13**: 129–141. 15 Apr 1961.

Löve, Áskell & Löve, Doris. Some nomenclatural changes in the European flora. I. Species and suprasspecific categories. Bot. Not. **114**: 33–47. II. Subspecific categories. 48–56. 30 Mar 1961.

Macbride, J. Francis. Flora of Peru [Boraginaceae, Verbenaceae, Labiatae, Nolanaceae]. Field Mus. Nat. Hist. Bot. Ser. **13**: 539–854. 9 Dec 1960.

MacDougall, T. *Epiphyllum ackermannii* in Mexico. Cact. Succ. Jour. **33**: 45, 46. Mar–Apr 1961.

MacKeever, Frank C. A variegated foilage form of *Commelina*. Rhodora **63**: 88–90. 29 Mar 1961.

McVaugh, Rogers. Eurphorbiaceae novae-galicianae. Brittonia **13**: 145–205. 15 Apr 1961.

Maguire, Bassett, Wurdack, John J. *et al.* The botany of the Guayana Highland—part IV (2). Mem. N. Y. Bot. Gard. **10**(4): 1–87. 15 Mar 1961.

Mason, Charles T. & Hevly, Richard H. Additions to the aquatic flora of Arizona. Madroño **16**: 32. 20 Jan 1961.

Mattos, Armando de & Coimbra, Adelmar F. Ensaios e apontamentos sôbre *Dalbergia nigra* Fr. Allem. Arq. Serv. Flor. Rio de Janeiro **11**: 157–174. 1957.

Mello, Luiz Emygdio de. Considerações sôbre *Rauvolfia sellowii* Muell. Arg. Bol. Mus. Rio de Janeiro **26**: 1–13. 18 Aug 1960.

Michalowski, Miguel. Generos de los arboles leguminosos del Paraguay. Bol. Minist. Agr. y Ganaderia, Paraguay **209**: 1–22. Feb 1927.

Moldenke, Harold N. Additional notes on the genus *Aegiphila*. XIV. Phytologia **7**: 451–464. 25 Apr 1961.

Moldenke, Harold N. Additional notes on the genus *Amasonia*. V. Phytologia **7**: 338–342. Feb [27 Jan] 1961.

Moldenke, Harold N. Additional notes on the genus *Baillonia*. I. Phytologia **7**: 342–345. Feb [27 Jan] 1961.

Moldenke, Harold N. Additional notes on the genus *Bouchea*. III. Phytologia **7**: 345–350. Feb [27 Jan] 1961.

Moldenke, Harold N. Additional notes on the genus *Casselia*. II. Phytologia **7**: 350–352. Feb [27 Jan] 1961.

Moldenke, Harold N. Additional notes on the genus *Castelia*. I. Phytologia **7**: 368. Feb [27 Jan] 1961.

Moldenke, Harold N. Additional notes on the genus *Chascanum*. III. Phytologia **7**: 353–362. Feb [27 Jan] 1961. IV. 369–376. 11 Mar 1961.

Moldenke, Harold N. Additional notes on the genus *Cornutia*. I. Phytologia **7**: 376–399. 11 Mar 1961.

Moldenke, Harold N. Additional notes on the genus *Petitia*. I. Phytologia **7**: 399–405. 11 Mar 1961.

Moldenke, Harold N. Additional notes on the genus *Petrea*. V. Phytologia **7**: 405–409. 11 Mar 1961. VI. 431–451. Apr 1961.

Moldenke, Harold N. Materials toward a monograph of the genus *Acantholippia*. Phytologia **7**: 326–338. Feb [27 Jan] 1961.

Moldenke, Harold N. Materials toward a monograph of the genus *Dipyrena*. Phytologia **7**: 321–326. Feb [27 Jan] 1961.

Moldenke, Harold N. Notes on new and noteworthy plants. XXVII. Phytologia **7**: 429, 430. 25 Apr 1961.

Monachino, Joseph. A new *Liriosma* [*crassa*] from Roraima. Brittonia **13**: 113–115. 30 Jan 1961.

Monachino, Joseph. Apocynaceae [*in* Botany of the Guayana Highland—part IV (2)]. Mem. N. Y. Bot. Gard. **10**:(4): 59–65. 15 Mar 1961.

Monachino, Joseph. The internal characteristics of winter buds. Bull. Torrey Club **87**: 419–421. 15 Dec 1960.

Monachino, Joseph. The wild flowers of the New York area. Gard. Jour. N. Y. Bot. Gard. **11**: 11–13, 21. Jan–Feb 1961.

Moore, Harold E. A remarkable new *Geranium* [*exallum*] from Ecuador. Brittonia **13**: 141–144. 15 Apr 1961.

Moore, Harold E. The genus *Aploleia* (Commelinaceae). Baileya **9**: 13–19. 31 Mar 1961.

Morton, Julia F. The cashew's brighter future. Econ. Bot. **15**: 57–78. Jan Mar [Apr] 1961.

Muller, Cornelius H. The live oaks of the series Virentes. Am. Midl. Nat. **65**: 17–39. Jan [Feb] 1961.

Mulligan, Gerald A. & Moore, Raymond J. Natural selection among hybrids between *Carduus acanthoides* and *C. nutans* in Ontario. Canad. Jour. Bot. **39**: 269–279. 20 Mar 1961.

Munz, Phillip A. The Lopezieae (Onagraceae). Brittonia **13**: 73–90. 30 Jan 1961.

Nevling, Lorin I. Aizoaceae, Portulacaceae [*in* Flora of Panama. Part IV, Fascicle 4]. Ann. Missouri Bot. Gard. **48**: 80–89. Feb [3 Apr] 1961.

Oswald, F. W. A new form of *Sassafras* [*albidum* f. *moldenkei*] from Long Island. Phytologia **7**: 321. Feb [27 Jan] 1961.

Ownbey, Gerald B. The genus *Argemone* in South America and Hawaii. Brittonia **13**: 91–109. 30 Jan 1961.

Pabst, G. F. J. As orquídeas do Rio Grande do Sul. Orquídea Rio de Janeiro **22**: 144–154. Jul–Aug 1960 [1961].

Pabst, G. F. J. Duas orquídeas de Saint Hilaire, pouco conhecidas. Orquídea Rio de Janeiro **22**: 132, 133. Jul–Aug 1960 [1961].

Pabst, Guido F. J. Orchidaceae novae riograndenses a cl. João Dutra descriptae vel nominatae sed nunquan luci editae—II. Orquídea Rio de Janeiro **22**: 156–165. Jul–Aug 1960 [1961]. [repr. from Sellowia, 1959.]

Pabst, Guido F. J. Uma orquídea rara no Brasil. Orquídea Rio de Janeiro **22**: 172, 173. Sep–Oct 1960 [1961].

Pease, Arthur Stanley. Campanular persistence. Rhodora **63**: 29, 30. 26 Jan 1961.

Raeder, Katherine. Phytolaccaceae [*in* Flora of Panami, Part IV, Fascicle 4]. Ann. Missouri Bot. Gard. **48**: 66–79. Feb [3 Apr] 1961.

Rahn, Knud. Chromosome numbers in some South American angiosperms. Bot. Tidsskr. **56**: 117–127. 9 Jul 1960.

Raymond, Marcel. Revision des Rhynchosporoideae d'Indo-Chine et de la Thaïlande. Nat. Canad. **88**: 8–24. Jan 1961.

Riley, H. P. & Bryant, T. R. The separation of nine species of the Iridaceae by paper chromatography. Am. Jour. Bot. **48**: 133–137. 15 Feb 1961.

Roe, *Sister* Margaret James. A taxonomic study of the indigenous Hawaiian species of the genus *Hibiscus* (Malvaceae). Pacif. Sci. **15**: 3–32. Jan 1961.

Rollins, Reed C. Notes on American *Rorippa* (Cruciferae). Rhodora **63**: 1–10. 26 Jan 1961.

Schweinfurth, Charles. Orchids of Peru. Fieldiana Bot. **30**: 533–786. 13 Jun 1960. 787–1005. 31 Mar 1961.

Sharsmith, Helen F. The genus *Hesperolinon* (Linaceae). Univ. Calif. Publ. Bot. **32**: 235–314. 20 Jan 1961.

Shaver, Jesse M. Notes on *Trillium luteum* (Muhl.) Harbison in Tennessee. Jour. Tenn. Acad. **36**: 12–22. Jan 1961.

Smith, Lyman B. Notes on Bromeliaceae, XVI. Phytologia **7**: 417–428. 25 Apr 1961.

Smith, Lyman B. The application of *Zamia pumila* L. Phytologia **7**: 417. 25 Apr 1961.

Smith, Stanley Jay. Biology of the Alleghany Indian Reservation and vicinity. Part 2: The seed plants. Bull. N. Y. St. Mus. **383**: 19–62. Jan 1961.

Soukup, J. Los géneros de las monocotiledóneas peruanas. Biota **3**: 172–180. Dec 1960.

Stebbins, G. Ledyard & Khush, Gurdev S. Variation in the organization of the stomatal complex in the leaf epidermis of monocotyledons and its bearing on their phylogeny. Am. Jour. Bot. **48**: 51–59. 23 Jan 1961.

Stern, Kingsley R. Revision of *Dicentra* (Fumariaceae). Brittonia **13**: 1–57. 30 Jan 1961.

Stevens, O. A. New records for North Dakota. Rhodora **63**: 39–46. Feb [27 Mar] 1961.

Steyermark, Julian A. A neglected *Camassia*. Brittonia **13**: 206–211. 15 Apr 1961.

Steyermark, Julian A. & Kucera, C. L. New combinations in grasses. Rhodora **63**: 24–26. 26 Jan 1961.

Stone, Benjamin C. The genus *Sararanga* (Pandanaceae). Brittonia **13**: 212–224. 15 Apr 1961.

Taylor, Ronald J. The genus *Delphinium* in Wyoming. Univ. Wyoming Publ. Sci. **24**: 9–21. 15 Jul 1960.

Teuscher, H. Four large-flowered Oncidiums from Ecuador. Am. Orchid Soc. Bull. **30**: 115–118. Feb 1961.

Teuscher, H. Two species of the genus *Barboscella*. Am. Orchid Soc. Bull. **30**: 50–52. Jan 1961.

Thomas, Joab L. *Schizocardia belizensis:* A species of Purdiaea (Cyrillaceae) from Central America. Jour. Arnold Arb. **42**: 110, 111. Jan 1961.

Thomas, Joab L. The cytology of some cultivated species of *Viburnum*. Jour. Arnold Arb. **42**: 157–164. 15 Apr 1961.

Thomas, Joab L. The genera of the Cyrillaceae and Clethraceae of the southeastern United States. Jour. Arnold Arb. **42**: 96–106. Jan 1961.

Travassos, Odette Pereira. Notas sôbre "typus" do herbário do Museu Nacional—Begoniaceae. Bol. Mus. Rio de Janeiro **25**: 1–8. 7 Jan 1960.

Tucker, John M. Studies in the *Quercus undulata* complex I. A preliminary statement. Am. Jour. Bot. **48**: 202–208. Mar [28 Feb] 1961.

Turner, B. L., Ellison, W. L. & King, R. M. Chromosome numbers in the Compositae IV. North American species, with phyletic interpretations. Am. Jour. Bot. **48**: 216–223. Mar [28 Feb] 1961.

Turner, B. L. & Irwin, H. S. Chromosome numbers of some Brazilian Leguminosae. Rhodora **63**: 16–19. 26 Jan 1961.

Turner, B. L. & Johnston, Marshall C. Chromosome numbers in the Compositae—III. Certain Mexican species. Brittonia **13**: 64–69. 30 Jan 1961.

Uhl, Charles H. The chromosomes of the Sempervivoideae (Crassulaceae). Am. Jour. Bot. **48**: 114–123. 15 Feb 1961.

Wilbur, Robert L. A new name for the puberulent sessile-leaved *Uvularia*. Rhodora **63**: 36–39. Feb [27 Mar] 1961.

Wood, Carroll E. A study of hybridization in *Dowingia* (Campanulaceae). Jour. Arnold Arb. **42**: 219–262. 15 Apr 1961.

Wood, Carroll E. The genera of Ericaceae in the southeastern United States. Jour. Arnold Arb. **42**: 10–80. Jan 1961.

Woodson, Robert E., Schery, Robert W. *et al.* Flora of Panama. Part IV, Fascicle 4 (Chenopodiaceae to Caryophyllaceae). Ann. Missouri Bot. Gard. **48**: 1–106. Feb [3 Apr] 1961.

Yeo, Peter F. Two *Bergenia* hybrids. Baileya **9**: 20–28. 31 Mar 1961.

Yuncker, T. G. New taxa of Peruvian Piperaceae. Brittonia **13**: 58–63. 30 Jan 1961.

ECOLOGY AND PLANT GEOGRAPHY

(See also under Fungi: **Ahmadjian, Cooke;** under Spermatophytes: **Lebrun**)

Billings, W. D. & Mark, A. F. Interactions between alpine tundra vegetation and patterned ground in the mountains of southern New Zealand. Ecology **42**: 18–31. Jan 1961.

Boyle, Lytton W. The ecology of *Sclerotium rolfsii* with emphasis on the role of saprophytic media [Symposium on *Sclerotium rolfsii*]. Phytopathology **51**: 117–119. Feb 1961.

Cooper, Arthur W. Relationships between plant life-forms and microclimate in southeastern Michigan. Ecol. Monogr. **31**: 31–59. Jan 1961.

Coupland, Robert T. A reconsideration of grassland classification in the northern Great Plains of North America. Jour. Ecol. **49**: 135–167. Feb 1961.

Daubenmire, R. A seven-year study of cone production as related to xylem layers and temperature in *Pinus ponderosa*. Am. Midl. Nat. **64**: 187–190. Jul [Aug] 1960.

Daubenmire, R. Vegetative indicators of rate of height growth in ponderosa pine. Forest Sci. **7**: 24–34. Mar 1961.

Dawson, E. Yale. A review of the ecology, distributions and affinities of the benthic flora of Baja California and vicinity. Syst. Zool. **9**: (3–4): 93–100. 1961.

Dawson, E. Yale. Changes in Palmyra Atoll and its vegetation through the activities of man, 1913–1958. Pacif. Nat. **1**(2): 1–52. Feb 1959.

De Gasperi, Luis J. B. Los trabajos de recuperación bioambiental de la estación biológica de Ingeniero Juarez (Formosa). Revista Agron. Noroeste Argent. **3**: 177–191. *pl. 1, 2.* Nov 1959.

Fowlie, Jack A. Ecology notes: *Oncidium jamaica*. Am. Orchid Soc. Bull. **30**: 223, 224. Mar 1961.

Gibor, Ahron & Meehan, William R. Diurnal variations in chlorophyll A content of some fresh-water algae. Ecology **42**: 156, 157. Jan 1961.

Grandtner, Miroslav M. La forêt de Beauséjour. Compté de Lévis. Quebéc. Etude phytosociologique. Fonds Recherch. Forest. Univ. Laval Contr. **7**: 1–62. *7 tab., 1 map.* 1960.

Grandtner, Miroslav M. Note sur le pinetum rigidae du Québec. Nat. Canad. **88**: 39–44. Feb 1961.

Hack, John T. & Goodlett, John C. Geomorphology and forest ecology of a mountain region in the central Appalachians. U. S. Geol. Survey Prof. Pap. **347**: 1–66. 1960.

Hartman, Richard T. & Himes, Craig L. Phytoplankton from Pymatuning reservoir in downstream areas of the Shenango River. Ecology **42**: 180–183. Jan 1961.

Hickey, Wayne C. Growth form of crested wheatgrass as affected by site and grazing. Ecology **42**: 173–176. Jan 1961.

Houston, Walter R. Some interrelations of sagebrush, soils, and grazing intensity in the Northern Great Plains. Ecology **42**: 31–38. Jan 1961.

Jameson, Donald A. Heat and desiccation resistance of tissue of important trees and grasses of the pinyon-juniper type. Bot. Gaz. **122**: 174–179. Mar [11 Apr] 1961.

Jantzen, Paul G. The ecology of a boggy marsh in Stafford County, Kansas. Emporia St. Res. Stud. **9**:(2): 1–46. Dec 1960.

Kilburn, Paul D. Effects of logging and fire on xerophytic forests in northern Michigan. Bull. Torrey Club **87**: 402–405. 15 Dec 1960.

Kilburn, Paul D. Summer phytoplankton at Coos Bay, Oregon. Ecology **42**: 165, 166. Jan 1961.

Kunkel, G. Un nuevo esquema ecológico. Biota **3**: 165–171. Dec 1960.

Lanner, Ronald M. Living stumps in the Sierra Nevada. Ecology **42**: 170–173. Jan 1961.

Lotspeich, Fredrick B., Secor, Jack B., Okazaki, Rose & Smith, Henry W. Vegetation as a soil-forming factor on the Quillayute physiographic unit in western Clallam County, Washington. Ecology **42**: 53–68. Jan 1961

Lutti, Ricardo. Ecologia y recuperación de la vegetación de algunas zonas aridas y semiaridas de América. Revista Agron. Noroeste Argent. **3**: 193–207. *pl. 1–13.* Nov 1959.

McCormick, Jack & Andresen, John W. Some effects of animals on the vegetation of the New Jersey pine barrens. Bull. Torrey Club **87**: 375–385. 15 Dec 1960.

Major, Jack. Use in plant ecology of causation, physiology and a definition of vegetation. Ecology **42**: 167–169. Jan 1961.

Mason, Herbert L. & Langenheim, Jean H. Natural selections as an ecological concept. Ecology **42**: 158–165. Jan 1961.

Mooney, H. A. & Billings, W. D. Comparative physiological ecology of arctic and alpine populations of *Oxyria digyna*. Ecol. Monogr. **31**: 1–29. Jan 1961.

Morello, Jorge H. & Saravia Toledo, Carlos. El bosque chaqueño. I. Paisaje Primitivo, paisaje natural y paisage cultural en el Oriente de Salta. Revista Agron. Noroeste Argent, **3**: 1–81. *pl. 1–46.* II. La ganaderia y el bosque en el Oriente de Salta. 209–258. *pl. 1–36.* Nov 1959.

Parker, Bruce C. & Bold, Harold C. Biotic relationships between soil algae and other microorganisms. Am. Jour. Bot. **48**: 185–197. 15 Feb 1961.

Pelton, John. An investigation of the ecology of *Mertensia ciliata* in Colorado. Ecology **42**: 38–52. Jan 1961.

Phillips, Ronald C. Environmental effect on leaves of *Diplanthera* du Petit-Thouars. Bull. Marine Sci. Gulf Carib. **10**: 346–353. Sep 1960.

Risi, J. & Zeller, E. Specific gravity of the wood of black spruce [*Picea mariana* (Mill.) B.S.P.] grown on a *Hylocomium-Cornus* site type. Fonds Recherch. Forest. Univ. Laval Contr. **6**: 1–70. 1960.

Roig, Fidel Antonio & Ruiz Leal, Adrian. El bosque muerto de Guandacol (La Rioja). Revista Agron. Noroeste Argent. **3**: 139–145. *pl. 1–4.* Nov 1959.

Ruiz Leal, Adrian. El desarollo de estructuras subcirculares en algunas plantas. Revista Agron. Noroeste Argent. **3**: 83–138. *pl. 1–39.* Nov 1959.

Sakagami, Shoichi F. An ecological perspective of Mareus Island with special reference to land animals. Pacif. Nat. **15**: 82–104. Jan 1961.

Sangster, A. G. & Dale, H. M. A preliminary study of differential pollen grain preservation. Canad. Jour. Bot. **39**: 35–43. *pl. 1.* 25 Jan 1961.

Stephenson, T. A. & Stephenson, Anne. Life between tide-marks in North America. IVa. Vancouver Island, I. Jour. Ecol. **49**: 1–29 *pl. 1–3.* Feb 1961

Takeuchi, Masayuki. The structure of the Amazonian vegetation. Jour. Fac. Sci. Univ. Tokyo Bot. **7**: 523–533. *pl. 1–35.* 30 Mar 1960.

Tester, John R. & Marshall, William H. A study of certain plant and animal interrelations on a native prairie in northwestern Minnesota. Occ. Pap. Minn. Mus. Nat. Hist. **8**: 1–51. 1961.

Van Denack, *Sister* Julia Marie. An ecological analysis of the sand dune complex in Point Beach State Forest, Two Rivers, Wisconsin. Bot. Gaz. **122**: 155–174. Mar [11 Apr] 1961.

Whittaker, R. H. Estimation of net primary production of forest and shrub communities. Ecology **42**: 177–180. Jan 1961.

Whittaker, R. H. Vegetation history of the Pacific coast states and the "central" significance of the Klamath Region. Madroño **16**: 5–23. 20 Jan 1961.

GENETICS
(including cytogenetics)

(See also under Spermatophytes: **Ahloowalia & Garber, Beetle, Bell & Garber, Bose & Janick, Hollister & Mitchell**; under Phytopathology: **Ellingboe, Johnson**)

Brockman, H. E. & DeBusk, A. Gib. Modifying factors of amino-acid antagonisms in a mutant of *Neurospora crassa.* Nature **189**: 940–942. 18 Mar 1961.

Campos, Filomena F. & Morgan, D. T. Genetic control of haploidy in *Capsicum frutescens* L. following crosses with untreated and x-rayed pollen. Cytologia **25**: 362–372. 25 Dec 1960.

Carnahan, H. L. & Hill, Helen D. Cytology and genetics of forage grasses. Bot. Rev. **27**: 1–162. Jan–Mar 1961.

Evans, H. J. Chromatid aberrations induced by gamma irradiation. I. The structure and frequency of chromatid interchanges in diploid and tetraploid cells of *Vicia faba*. Genetics **46**: 257–275. II. Non randomness in the distribution of chromatid aberrations in relation to chromsome length in *Vicia faba* root-tip cells. 277–289. 30 Mar 1961.

Gerstel, D. U. Chromosomal control of preferential pairing in *Nicotiana*. Science **133**: 579, 580. 24 Feb 1961.

Grun, Paul. Early stages in the formation of internal barriers to gene exchange between diploid species of *Solanum*. Am. Jour. Bot. **48**: 79–89. 23 Jan 1961.

Jaranowski, Julian K. Semisterility in the interspecific hybrid *Melilotus polonica* × *M. alba*. Am. Jour. Bot. **48**: 28–35. 23 Jan 1961.

Knott, D. R. The inheritance of rust resistance. VI. The transfer of stem rust resistance from *Agropyron elongatum* to common wheat. Canad. Jour. Pl. Sci. **41**: 109–123. *pl. 1* 25 Jan 1961.

Lindegren, Carl C. A hypothesis concerning the mechanism of gene action. Nature **189**: 959–965. 25 Mar 1961.

Maguire, Marjorie P. Pachytene pairing failure in corn in two inbred lines and their hybrid. Genetics **46**: 135–142. 28 Feb 1961.

Nelson, R. R. & Ulistrup, A. J. The inheritance of pathogenicity in *Cochliobolus carbonum*. Phytopathology **51**: 1, 2. 20 Jan 1961.

Phillips, L. L. The cytogenetics of speciation in Asiatic cotton. Genetics **6**: 77–83. 31 Jan 1961.

Sen, Nirad K. & Murty A. S. N. Inheritance of seed weight in green gram (*Phaseolus aureus* Roxb.). Genetics **45**: 1559–1562. 31 Dec 1960.

Steiner, Erich. Incompatibility in the complex-heterozygotes of *Oenothera*. Genetics **46**: 301–315. 30 Mar 1961.

Tiiu, Vaharu. Modification of ultraviolet-induced mutation frequency in *Neurospora crassa*. Genetics **46**: 247–256. 30 Mar 1961.

Vajrabhaya, Thavorn & Randolph, L. F. Chromosome inheritance in pentaploid and aneuploid Cattleyas. Am. Orchid. Soc. Bull. **30**: 209–213. Mar 1961.

Wagenaar, E. B. Cytological studies of the development of metaphase I in hybrids between *Triticum timopheevi* Zhuk. and *T. durum* Desf. Canad. Jour. Bot. **39**: 81–108. *pl. 1*. 25 Jan 1961.

MORPHOLOGY

(including anatomy and cytology in part)

(see also under Algae: **Norris**; under Fungi: **Snider**; under Spermatophytes: **Stebbins & Khush**; under Plant Physiology: **Steward**)

Al-Talib, Khalil H. & Torrey, John G. Sclereid distribution in the leaves of *Pseudotsuga* under natural and experimental conditions. Am. Jour. Bot. **48**: 71–79. 23 Jan 1961.

Atkinson, Lenette R. The Schizaeaceae: The gametophyte of *Mohria*. Phytomorphology **10**: 351–367. Dec 1960 [Jan 1961].

Bailey, I. W. Comparative anatomy of the leaf-bearing Cactaceae, II. Structure and distribution of sclerenchyma in the phloem of *Pereskia*, *Pereskiopsis* and *Quiabentia*. Jour. Arnold Arb. **42**: 144–156. *pl. 1–6*. 15 Apr 1961.

Bakerspigel, A. Nuclear structure and division in the Fungi Imperfecti II. *Scopulariopsis brevicaulis*. Cytologia **25**: 344–351. 25 Dec 1960.

Ball, Ernest. Cell division in living shoot apices. Phytomorphology **10**: 377–396. Dec 1960 [Jan 1961].

Berlyn, Graeme P. Factors affecting the incidence of reaction tissue in *Populus deltoides* Bartr. Iowa St. Univ. Jour. Sci. **35**: 367–424. 15 Feb 1961.

Browne, Edward T. Morphological studies in *Aletris*. I. Development of the ovule, megaspores and megagametophyte of *A. aurea* and their connection with the systematics of the genus. Am. Jour. Bot. **48**: 143–147. 15 Feb 1961.

Davis, Edward L. Medullary bundles in the genus *Dahlia* and their possible origin. Am. Jour. Bot. **48**: 108–113. 15 Feb 1961

Dehnel, George S. Abnormal stomatal development in foliage leaves of *Begonia aridicaulis*. Am. Jour. Bot. **48**: 129–133. 15 Feb 1961.

Erickson, Ralph O. Probability of division of cells in the epidermis of the *Phleum* root. Am. Jour. Bot. **48**: 268–274. Mar [28 Feb] 1961.

Forward, Dorothy F. & Nolan, Norah J. Growth and morphogenesis in the Canadian forest species. IV. Radial growth in branches and main axis of *Pinus resinosa* Ait. under conditions of open growth, suppression, and release. Canad. Jour. Bot. **39**: 385–409. V. Further studies of wood growth in branches and main axis of *Pinus resinosa* Ait. under conditions of open growth, suppression, and release. 411–436. 20 Mar. 1961.

Goodwin, Donna C. Morphogenesis of the sporangium of *Comatricha*. Am. Jour. Bot. **48**: 148–154. 15 Feb 1961.

James, Lois E. & Kyhos, Donald W. The nature of the fleshy shoot of *Allenrolfea* and allied genera. Am. Jour. Bot. **48**: 101–108. 15 Feb 1961.

Kaeiser, Margaret. Shoot apices in two hybrid junipers. Trans. Ill. Acad. **53**: 132–140. 1960 [10 Apr 1961].

Kasapligil, Baki. Foliar xeromorphy of certain geophytic monocotyledons. Madroño **16**: 43–70. 18 Apr 1961.

McGahan, Merritt W. Studies on the seed of banana. I. Anatomy of the seed and embryo of *Musa balbisiana*. Am. Jour. Bot. **48**: 230–238. Mar [28 Feb] 1961.

Miksche, Jerome P. Developmental vegetative morphology of *Glycine max*. Agron. Jour. **53**: 121–128. Apr 1961.

Mohan, Ram H. Y. Seed development in *Adhatoda vasica* Nees. Canad. Jour. Bot. **39**: 207–214. 25 Jan 1961.

Moreira, Alvaro Xavier. Considerações sôbre a morfologia polínica. Trimorfismo do pólen de *Ceiba erianthos* K. Sch. Bol. Mus. Rio de Janeiro. **24**: 1–6. 2 Jan 1960.

Nayar, B. K. Morphology of the gametophyte of *Quercifilix* Copeland. Lloydia **23**: 102–108. Dec 1960 [10 Apr 1961].

Olah, L. v. Cytological and morphological investigations in *Rafflesia arnoldi* R. Br. Bull. Torrey Club **87**: 406–416. 15 Dec 1960.

Paolillo, Dominick J. & Gifford, Ernest M. Plastochronic changes and the concept of apical initials in *Ephedra altissima*. Am. Jour. Bot. **48**: 8–16. 23 Jan 1961.

Rippon, John W. & Scherr, George H. Induced dimorphism in dermatophytes. Mycologia **51**: 902–914. 1959 [14 Apr 1961].

Ross, Ian K. Further studies on meiosis in the Myxomycetes. Am. Jour. Bot. **48**: 244–248. Mar [28 Feb] 1961.

Schroeder, C. A. Some morphological aspects of fruit tissues grown in vitro. Bot. Gaz. **122**: 198–204. Mar [11 Apr] 1961.

Seaman, W. L., Larson, R. H. & Walker, J. C. Tinsel-type structure in flagella of zoospores associated with cabbage clubroot tissue. Nature **190**: 186, 187. 8 Apr 1961.

Shellhorn, Samuel J. & Hull, Herbert M. A six-dye staining schedule for sections of mesquite and other desert plants. Stain Tech. **35**: 69–71. Mar 1961.

Srivastava, L. M. & Esau, K. Relation of dwarfmistletoe (*Arceuthobium*) to the xylem tissue of conifers. I. Anatomy of parasite sinkers and their connection with host xylem. Am. Jour. Bot. **48**: 159–167. 15 Feb 1961. II. Effect of the parasite on the xylem anatomy of the host. 209–215. Mar [28 Feb] 1961.

Sun, C. N. The fine structure of plant mitochondria. Cytologia **25**: 493–501. 25 Dec 1960.

Tanaka, R. & Kamemoto, H. Meitotic chromosome behavior in diploid and polyploid *Vanda* orchid hybrids. Cytologia **25**: 405–418. 25 Dec 1960.

Tolbert, Robert J. A seasonal study of the vegetative shoot apex and the pattern of pith development in *Hibiscus syriacus*. Am. Jour. Bot. **48**: 249–255. Mar [28 Feb] 1961.

Tsunewaki, Koichiro & Jenkins, B. Charles. A comparative study of various methods of root-tip preparation in screening wheat aneuploids. Cytologia **25**: 373–380. 25 Dec 1960.

Tucker, Shirley C. Phyllotaxis and vascular organization of the carpels in *Michelia fuscata*. Am. Jour. Bot. **48**: 60–71. 23 Jan 1961.

Venkataraman, G. S. & Mehta, S. C. The thecal structure of *Peridinium cinctum*. Lloydia **23**: 115–117. Dec 1960 [10 Apr 1961].

Ward, Max. Vegetative propagation from intact leaves of *Polytrichum commune* Hedw. Phytomorphology **10**: 325–329. Dec 1960 [Jan 1961].

White, Richard A. Vessels in roots of *Marsilea*. Science **133**: 1073, 1074. 7 Apr 1961.

PALEOBOTANY

Banks, Harlan P. Notes on Devonian lycopods. Senckenb. Leth. **41**: 59–88. 29 Aug 1960.

Becker, Herman F. Additions to the Tertiary Ruby Paper Shale flora of southwestern Montana. Bull. Torrey Club. **87**: 386–396. 15 Dec 1960.

Becker, Herman F. Oligocene plants from the Upper Ruby River Basin in southwestern Montana. Geol. Soc. Am. Mem. **82**: 1–128. *pl. 1–32*. 9 Jan 1961.

Becker, Herman F. Palaeobotanical record of solar change. N. Y. Acad. Conference Bull. p. 21, 22. 27 Jan 1961. (Abstract)

Beetham, Nellie & Niering, William A. A pollen diagram from southeastern Connecticut. Am. Jour. Sci. **259**: 69–75. Jan 1961.

Bharadwaj, D. C. & Venkatachala, B. S. On *Protosalvinia arnoldii* n. sp. from Upper Devonian of Kentucky, U.S.A. Senckenb. Leth. **41**: 27–35. 29 Aug 1960.

Boureau, Edouard & Salard, Marguerite. Contribution à l'étude paléoxylologique de la Patagonie [*Nothofagoxylon kraeuseli* sp. nov.]. Senckenb. Leth. **41**: 297–315. 29 Aug 1960.

Davis, Margaret B. The problem of rebedded pollen in late-glacial sediments at Taunton, Massachusetts. Am. Jour. Sci. **259**: 211–222. Mar 1961.

Gray, Jane. Early Pleistocene paleoclimatic record from Sonoran Desert, Arizona. Science **133**: 38, 39. 6 Jan 1961.

Leisman, Gilbert A. Further observations on the structure of *Selaginellites crassicinctus*. Am. Jour. Bot. **48**: 224–229. Mar [28 Feb] 1961.

Okamura, R. T. & Forbes, J. C. Occurrence of silicified wood in Hawaii. Am. Jour. Sci. **259**: 229, 230. Mar 1961.

Prakash, U. & Barghoorn, Elso S. Miocene fossil woods from the Columbia basalts of central Washington. Jour. Arnold Arb. **42**: 165–203. *pl. 1–8*. 15 Apr 1961.

Radforth, Norman W. & Walton, John. On some fossil plants from the Minto Coalfield, New Brunswick. Senckenb. Leth. **41**: 101–119. 29 Aug 1960.

Rouse, Glenn E. & Mathews, W. H. Radioactive dating of Tertiary plant-bearing deposits. Science **133**: 1079, 1080. 7 Apr 1961.

Smiley, Charles L. A record of *Paulownia* [*columbiana* sp. nov.] in the Tertiary of North America. Am. Jour. Bot. **48**: 175–179. 15 Feb 1961.

PHYTOPATHOLOGY

(See also under Fungi: **Hardison et al., Turner**; under Genetics: **Nelson & Ullstrup**)

Ark, Peter A. & Thompson, James P. Detection of hairy root pathogen, *Agrobacterium rhizogenes*, by the use of fleshy roots. Phytopathology **51**: 69–71. 20 Jan 1961.

Aycock, Robert. Summation [Symposium on *Sclerotium rolfsii*]. Phytopathology **51**: 107, 108. 20 Feb 1961.

Bailey, A. G. & Eijnatten, C. van. Corn gray spot caused by *Piricularia grisea*. Phytopathology **51**: 197, 198. 15 Mar 1961.

Baker, Kenneth F., Dimock, A. W. & Davis, L. H. Cause and prevention of the rapid spread of the *Ascochyta* disease of *Chrysanthemum*. Phytopathology **51**: 96–101. 15 Feb 1961.

Basu, P. K. *Verticillium* disease of strawberries. Canad. Jour. Bot. **39**: 165–196. *pl. 1*. 25 Jan 1961.

Berry, Robert W. & Futrell, Maurice C. Toxin production by *Helminthosporium victoriae* on synthetic media containing different nitrogen sources. Phytopathology **51**: 177–179. 15 Mar 1961.

Berry, S. Z. & Thomas, C. A. Influence of soil temperature, isolates, and method of inoculation on resistance of mint to *Verticillium* wilt. Phyopathology **51**: 169–174. 15 Mar 1961.

Bier, John E. The relation of bark moisture to the development of canker diseases caused by native, facultative parasites IV. Pathogenicity studies of *Cryptodiaporthe salicella* (Fr.) Petrak, and *Fusarium lateritium* Nees., on *Populus trichocarpa* Torrey and Gray, *P. 'robusta'*, *P. tremuloides* Michx., and *Salix* sp. Canad. Jour. Bot. **39**: 139–144. *pl. 1*. V. Rooting behavior and disease vulnerability in cuttings of *Populus trichocarpa* Torrey and Gray, and *P. 'robusta'*. 145–154. *pl. 1, 2*. 25 Jan 1961.

Cadman, C. H. & Lister, R. M. Relationship between tomato ringspot and peach yellow bud mosaic viruses. Phytopathology **51**: 29–31. 20 Jan 1961.

Carter, J. F. & Dickson, J. G. Sporulation of *Pyrenophora bromi* in culture. Phytopathology **51**: 204–206. 15 Mar 1961.

Cation, Donald. A comparison of virus isolates, dwarf-fruit and spy 227-lethal. Phytopathology **51**: 104–106. 20 Feb 1961.

Čéch, M., Králík, O. & Blattný, C. Rod-shaped particles associated with virosis of spruce. Phytopathology **51**: 183–185. 15 Mar 1961.

Cooper, W. E. Strains of, resistance to, and antagonists of *Sclerotium rolfsii* [Symposium on *Sclerotium rolfsii*]. Phytopathology **51**: 113–116. 20 Feb 1961.

Cormack, M. W. & Moffatt, J. E. Factors influencing storage decay of sugar beets by *Phoma betae* and other fungi. Phytopathology **51**: 3–5. 20 Jan 1961.

Davey, C. B. & Papavizas, G. C. *Aphanomyces* root rot of peas as affected by organic and mineral soil amendments. Phytopathology **51**: 131, 132. 20 Feb 1961.

Dukes, P. D. & Apple, J. L. Chemotaxis of zoospores of *Phytophthora parasitica* var. *nicotianae* by plant roots and certain chemical solutions. Phytopathology **51**: 195–197. 15 Mar 1961.

Dyson, Joan Gwyneth & Chessin, M. Effect of auxins on virus-induced leaf abscission. Phytopathology **51**: 195. 15 Mar 1961.

Edgington, L. V., Corden, M. E. & Dimond A. The role of pectic substances in chemically induced resistance to *Fusarium* wilt of tomato. Phytopathology **51**: 179–182. 15 Mar 1961.

Ellingboe, Albert H. Somatic recombination in *Puccinia graminis* var. *tritici*. Phytopathology **51**: 13–15. 20 Jan 1961.

Carren, Kenneth H. Control of *Sclerotium rolfsii* through cultural practices [Symposium on *Sclerotium rolfsii*]. Phytopathology **51**: 120–124. 20 Feb 1961.

Goth, R. W. & Wilcoxson, Roy D. Red clover: A new host for potato virus X. Phytopathology **51**: 132, 133. 20 Feb 1961.

Hardison, John R. Evidence against *Fusarium poae* and *Siteroptes graminum* as causal agents of silver top of grasses. Mycologia **51**: 712–728. 1959. [17 Mar 1961].

Harrison, A. L. Control of *Sclerotium rolfsii* with chemicals [Symposium on *Sclerotium rolfsii*]. Phytopathology **51**: 124–128. 20 Feb 1961.

Helton, A. W. & Konicek, D. E. Effects of selected *Cytospora* isolates from stone fruits on certain stone fruit varieties. Phytopathology **51**: 152–157. 15 Mar 1961.

Hendrix, James W. Soil transmission of tobacco ringspot virus. Phytopathology **51**: 194. 15 Mar 1961.

Hine, Richard B. The role of amygdalin breakdown in the peach replant problem. Phytopathology **51**: 10–13. 20 Feb 1961.

Ikenberry, G. J. & Young, H. C. A leaf blight of Cimarron oats. Phytopathology **51**: 80–83. 20 Feb 1961.

Iton, E. F. *Ceratostomella* wilt in cacao in Trinidad. Jour. Agr. Soc. Trinidad, Tobago **50**: 461–464. Dec 1960.

Jackson, Curtis R. *Cercospora* leafspot of statice. Phytopathology **51**: 129, 130. 20 Feb 1961.

Johnson, T. Man-guided evolution in plant rusts. Science **133**: 357–362. 10 Feb 1961.

Jones, John P. A weed host of *Xanthomonas phaseoli* var. *sojense*. Phytopathology **51**: 206. 15 Mar 1961.

Kaufmann, M. J., Drolsom, P. N. & Nielsen, E. L. Reaction of smooth bromegrass to seedling pathogens. Agron. Jour. **53**: 77–80. Apr 1961.

Kavanagh, Thomas. Inoculating barley seedlings with *Ustilago nuda* and wheat seedlings with *U. tritici*. Phytopathology **51**: 175–177. 15 Mar 1961.

Kavanagh, Thomas. Temperature in relation to loose smut in barley and wheat. Phytopathology **51**: 189–193. 15 Mar 1961.

Kelman, Arthur & Person, L. H. Strains of *Pseudomonas solanacearum* differing in pathogenicity to tobacco and peanut. Phytopathology **51**: 158–161. 15 Mar 1961.

Krog, Norman E., Le Tourneau, Duane & Hart, Helen. The sugar content of wheat leaves infected with stem rust. Phytopathology **51**: 75–77. 20 Feb 1961.

Le Tourneau, Duane & Buer, Lawrence. The toxicity of some chlorinated phenols and aryloxyalkanecarboxylic acids to *Verticillium albo-atrum*. Phytopathology **51**: 128, 129. 20 Feb 1961.

Linder, R. C., Kirkpatrick, Hugh C. & Weeks, T. E. Effect of source host on infectivity of tobacco mosaic virus isolates. Phytopathology **51**: 15, 16. 20 Jan 1961.

Lownsbery, B. F. Factors affecting population levels of *Criconemoides xenoplax*. Phytopathology **51**: 101–103. 20 Feb 1961.

McLean, John G. Le Tourneau, Duane J. & Guthrie, James W. Relation of histochemical tests for phenols to *Verticillium* wilt resistance of potatoes. Phytopathology **51**: 84–89. 20 Feb 1961.

Meredith, D. S. Fruit-spot ('speckle') of Jamaican bananas caused by *Deightoniella torulosa* (Syd.) Ellis. I. Symptoms of disease and studies on pathogenicity. Brit. Mycol. Soc. Trans. **44**: 95–104. *pl. 8, 9*. Mar 1961.

Morton, Donald J. Trypan blue and boiling lactophenol for staining and clearing barley tissues infected with *Ustilago nuda*. Phytopathology **51**: 27–29. 20 Jan 1961.

Nayudu, M. V. & Walker, J. C. In vitro nutrition of the tomato bacterial spot organism. Phytopathology **51**: 32–34. 20 Jan 1961.

Nelson, Harry. *Fusarium* wilt [of orchids] found in California. Am. Orchid Soc. Bull. **30**: 222. Mar 1961.

Orellana, R. G. Leaf spot of sesame caused by *Cylindrosporium sesami*. Phytopathology **51**: 89–92. 20 Feb 1961.

Papavizas, G. C. & Davey, C. B. Isolation of *Thielaviopsis basicola* from bean rhizosphere. Phytopathology **51**: 92–96. 20 Feb 1961.

Parmeter, J. R. & Hood, J. R. The use of *Fusarium* culture filtrate media in the isolation of Fusaria from soil. Phytopathology **51**: 164–168. 15 Mar 1961.

Peterson, Roger S. Western gall rust cankers in lodgepole pine. Jour. Forest. **59**: 194–196. Mar 1961.

Pound, Glenn S. & Singh, G. P. The effect of air temperature on multiplication of tobacco mosaic virus in susceptible and resistant pepper. Phytopathology **50**: 803–807. Nov 1960.

Powell, N. T. & Moore, E. L. A technique for inoculating leaves with root-knot nematodes. Phytopathology **51**: 201, 202. 15 Mar 1961.

Raymond, F. L. & Reid, J. Dieback of balsam fir in Ontario. Canad. Jour Bot. **39**: 233–251. *pl. 1*. 20 Mar 1961.

Schindler, A. F., Stewart, Robert N. & Semeniuk, Peter. A synergistic *Fusarium*-nematode interaction in carnations. Phytopathology **51**: 143–146. 15 Mar 1961.

Scott, H. A. Serological detection of barley stripe mosaic virus in single seeds and dehydrated leaf tissues. Phytopathology **51**: 200, 201. 15 Mar 1961.

Shaw, C. G. & Harris, M. R. Important diseases and decays of trees native to Washington. Wash. St. Univ. Agr. Ext. Bull. **540**: 1–35. Jul 1960.

Smiley, J. H. & Stokes, G. W. Resistance to the wildfire disease in relation to the gene-chromosome set ratio in tobacco. Phytopathology **51**: 174, 175. 15 Mar 1961.

Snow, Glenn A. Artificial inoculation of longleaf pine with *Scirrhia acicola*. Phytopathology **51**: 186–188. 15 Mar 1961.

Sondheimer, Ernest. Possible identity of a fungitoxic compound from carrot roots. Phytopathology **51**: 71, 72. 20 Jan 1961.

Stouffer, Richard F. & Ross, A. Frank. Effect of temperature on the multiplication of potato virus X in the presence and absence of potato virus Y. Phytopathology **51**: 5–9. 20 Jan 1961.

Stover, R. H., Hildreth, R. C. & Thornton, N. C. Studies on *Fusarium* wilt of bananas. VII. Field control Canad. Jour. Bot. **39**: 197–206. *pl. 1–3*. 25 Jan 1961.

Swenson, K. G. & Carpenter, G. P. Transmission of the ringspot virus of stone fruits from squash to squash by foilage contact. Phytopathology **51**: 68, 69. 20 Jan 1961.

Templeton, G. E. Local infection of rice florets by the rice kernel smut organism, *Tilletia horrida*. Phytopathology **51**: 130, 131. 20 Feb 1961.

Thorn, G. D. The fungicidal activity of acrolein phenylhydrazone and related compounds against rust. Phytopathology **51**: 77–80. 20 Feb 1961.

Torgeson, Dewayne C. The fungicidal activity of (aminoalkyl) pyrenes. Contr. Boyce Thompson Inst. **21**: 21–26. Jan–Mar 1961.

Torgeson, Dewayne C., Hensley, W. H. & Lambrech, J. A. Polyacracylic methylmercaptoimidazolines as foliage fungicides. Contr. Boyce Thompson Inst. **21**: 27–31. Jan–Mar 1961.

Torgeson, Dewayne C. & Lindberg, C. G. A greenhouse method for evaluation of chemicals to control apple powdery mildew. Contr. Boyce Thompson Inst. **21**: 33, 34. Jan–Mar 1961.

Tousson, T. A. & Snyder, William C. The pathogenicity, distribution, and control of two races of *Fusarium* (*Hypomyces*) *solani* f. *cucurbitae*. Phytopathology **51**: 17–22. 20 Jan 1961.

Vaartaja, O., Cram, W. H. & Morgan, G. A. Damping-off etiology especially in forest nurseries. Phytopathology **51**: 35–42. 20 Jan 1961.

Van Gundy, S. D. & Martin, J. P. Influence of *Tylenchulus semipenetrans* on the growth and chemical composition of sweet orange seedlings in soils of various exchangeable cation ratios. Phytopathology **51**: 146–151. 15 Mar 1961.

Viglierchio, David R. Attraction of parasitic nematodes by plant root emanations. Phytopathology **51**: 136–142. 15 Mar 1961.

Wallis, G. W. Infection of Scots pine roots by *Fomes annosus*. Canad. Jour. Bot. **39**: 109–121. 25 Jan 1961.

Weintraub, H. Purification and electron microscopy of the peach yellow bud mosaic virus. Phytopathology **51**: 198–200. 15 Mar 1961.

Wilson, Coyt. Comments on part I: Some gaps in our knowledge of *Sclerotium rolfsii* [Symposium on *Sclerotium rolfsii*]. Phytopathology **51**: 116, 117. 20 Feb 1961.

Wood, R. K. S. *Verticillium* wilt of tomatoes—the role of pectic and cellulolytic enzymes. Ann. Appl. Biol. **49**: 120–139. Mar 1961.

Yarwood, C. E. Uredospore production by *Uromyces phaseoli*. Phytopathology **51**: 22–27. 20 Jan 1961.

Zimmer, David E. & Schafer, John F. Relation of temperature to reaction type of *Puccinia coronata* on certain oat varieties. Phytopathology **51**: 202, 203. 15 Mar 1961.

Zummo, Natale & Plakidas, A. G. Spread of petal blight of camellias by air-borne ascospores of *Sclerotinia camelliae*. Phytopathology **51**: 69. 20 Jan 1961.

PLANT PHYSIOLOGY

(See also under Algae: **Burkholder et al.**; under Bryophytes: **Sharma et al.**; under Fungi: **Berry**; **Miller & Reid**, **Vogel**).

Abeles, Frederick B., Brown, A. H. & Mayne, B. C. Stimulation of the hill reaction by carbon dioxide. Pl. Physiol. **36**: 202–207. Mar 1961.

Adams, Donald F. & Emerson, Merle T. Variations in starch & total polysaccharide content of *Pinus ponderosa* needles with fluoride fumigation. Pl. Physiol. **36**: 261–265. Mar 1961.

Ahmadjian, Vernon & Reynolds, John T. Production of biologically active compounds by isolated lichenized fungi. Science **133**: 700. 10 Mar 1961.

Akazawa, T. & Wada, K. Analytical study of ipomeamarone & chlorogenic acid alterations in sweet potato roots infected by *Ceratocystis fimbriata*. Pl. Physiol. **36**: 139–144. Mar 1961.

Albert, Luke S. & Wilson, Curtis M. Effect of boron on elongation of tomato root tips. Pl. Physiol. **36**: 244–251. Mar 1961.

Al-Doory, Yousef. The effect of various substances on the oxygen uptake of *Rhizopus oryzae*. Mycologia **51**: 851–854 1959. [14 Apr 1961].

Allan, Robert E., Vogel, O. A. & Craddock, J. C. Effect of gibberellic acid upon seedling emergence of slow and fast emerging wheat varieties. Agron. Jour. **53**: 30–32. Jan–Feb 1961.

Alston, R. E. & Irwin, H. S. The comparative extent of variation of free amino acids and certain "secondary" substances among *Cassia* species. Am. Jour. Bot. **48**: 35–39. 23 Jan 1961.

Audette, R. C. S., Baxter, R. M. & Walker, G. C. A study of the lipid content of *Trichophyton mentagrophytes*. Canad. Jour. Microbiol. **7**: 282, 283. Apr 1961.

Avers, Charlotte J. Histochemical localization of enzyme activities in root meristem cells. Am. Jour. Bot. **48**: 137–143. 15 Feb 1961.

Bach, Michael K. & Fellig, J. Correlation between inactivation of 2,4-dichlorophenoxyacetic acid and cessation of callus growth in bean stem sections. Pl. Physiol. **36**: 89–91. Jan 1961.

Bach, Michael K. & Fellig, J. Ubiquity of stimulation of endogenous respiration by purines and purine analogs. Pl. Physiol. **36**: 85–88. Jan 1961.

Baker, James E. A study of the action of maleic hydrazide on processes of tobacco and other plants. Physiol. Plant. **14**: 76–88. 1961.

Baker, James E. & Thompson, John F. Assimilation of ammonia by nitrogen-starved cells of *Chlorella vulgaris*. Pl. Physiol. **36**: 208–212. Mar 1961

Basler, Eddie & Nakazawa, Keishi. Some effects of 2,4-dichlorophenoxyacetic acid on nucleic acids of cotton cotyledon tissue. Bot. Gaz. **122**: 228–232. Mar [11 Apr] 1961.

Borow, A., Jefferys, E. G., Kessell, R. H. J., Lloyd, Eithne C., Lloyd, P. B. & Nixon, I. S. The metabolism of *Gibberella fujikuroi* in stirred culture. Canad. Jour. Microbiol. **7**: 227–276 *pl. 1*. Apr 1961.

Britten, E. J. The influence of genotype and temperature on flowering in *Trifolium repens*. Agron. Jour. **53**: 11–14. Jan–Feb 1961.

Brown, J. C., Tiffin, L. O., Specht, A. W. & Resnicky, J. W. Iron absorption by roots as affected by plant species and concentration of chelating agent. Agron. Jour. **53**: 81–85. Apr 1961.

Brown, J. C., Tiffin, L. O., Specht, A. W. & Resnicky, J. W. Stability and concentration of metal chelates, factors in iron chlorosis of plants. Agron. Jour. **53**: 85–90. Apr 1961.

Brown, Stewart A. Studies of lignin biosynthesis using isotopic carbon. IX Taxonomic distribution of the ability to utilize tyrosine in lignification. Canad. Jour. Bot. **39**: 253–258. 20 Mar 1961.

Bünning, E. Endogenous rhythms and morphogensis. Canad. Jour. Bot. **39**: 461–467. 20 Mar 1961.

Carter, Mason C. & Naylor, A. W. Studies on an unknown metabolic product of 3-amino-1,2,4-triazole. Physiol. Plant. **14**: 20–27. 1961.

Carter, Mason C. & Naylor, Aubrey W. The effect of 3-amino-1,2,4-triazole upon the metabolism of carbon labeled sodium bicarbonate glucose, succinate, glycine, and serine by bean plants. Physiol. Plant. **14**: 62–71. 1961.

Cherry, Joe H. & Hageman, R. H. Nucleotide & ribonucleic acid metabolism of corn seedlings. Pl. Physiol. **36**: 163–168. Mar 1961.

Ching, T. M. Respiration of forage seed in hermetically sealed cans. Agron. Jour. **53**: 6–8. Jan–Feb 1961.

Couey, H. Melvin & Smith, Frederick G. Effect of cations on germination & germ tube development of *Puccinia coronata* uredospores. Pl. Physiol. **36**: 14–19. Jan 1961.

Crosby, Donald G., Berthold, Robert V. & Spencer, Roy. Naturally occurring growth substances. II. An improved straight growth test & its applications. Pl. Physiol. **36**: 48–51. Jan 1961.

Curtis, Roy W. Studies on response of bean seedlings and corn roots to malformin. Pl. Physiol. **36**: 37–43. Jan 1961.

Danforth, W. F. & Wilson, B. W. The endogenous metabolism of *Euglena gracilis*. Jour. Gen. Microbiol. **24**: 95–105. Jan 1961.

Davidson, O. Wesley. Principles of orchid nutrition. Am. Orchid Soc. Bull. **30**: 277–285. Apr 1961.

Davis, R. M. & Lingle, J. C. Basis of shoot response to root temperature in tomato. Pl. Physiol. **36**: 153–162. Mar 1961.

Delwiche, C. C., Johnson, C. M. & Reisenauer, H. M. Influence of cobalt on nitrogen fixation by *Medicago*. Pl. Physiol. **36**: 73–78. Jan 1961.

Devlin, Robert M. & Jackson, William T. Effect of *p*-chlorophenoxyisobutyric acid on rate of elongation of root hairs of *Agrostis alba*. L. Physiol. Plant. **14**: 40–48. 1961.

DiPalma, Joseph R., Mohl, Robert & Best, William. Action potential and contraction of *Dionaea muscipula* (Venus Flytrap). Science: **133**: 878, 879. 24 Mar 1961.

Dybing C. Dean & Currier, H. B. Foliar penetration by chemicals. Pl. Physiol. **36**: 169–174. Mar 1961

Einspahr, Dean W. & Buijtenen, J. P. van. The influence of gibberellic acid on growth and fiber length of quaking aspen. Forest Sci. **7**: 43–51. Mar 1961.

Erwin, D. C. & Katznelson, H. Studies on the nutrition of *Phytophthora cryptogea*. Canad. Jour. Microbiol. **7**: 15–25. Feb 1961.

Evans, William R. & Axelrod, Bernard. Pyrimidine metabolism in germinating seedlings. Pl. Physiol. **36**: 9–13. Jan 1961.

Fang, S. C., Teeny, Fuad & Butts, Joseph S. Effect of 2,4-dichlorophenoxyacetic acid on utilization of labeled acetate by bean leaf & stem tissues. Pl. Physiol. **36**: 192–196. Mar 1961.

French, Richard C. Stimulation of uredospore germination in wheat stem rust by terpenes and related compounds. Bot. Gaz. **122**: 194–198. Mar [11 Apr] 1961.

Fried, Maurice, Oberländer, Hans E. & Noggle, J. C. Kinetics of rubidium absorption & translocation by barley. Pl. Physiol. **36**: 183–191. Mar 1961.

Friend, D. J. C. Control of chlorophyll content by daylength in leaves of Marquis wheat. Canad. Jour. Bot. **39**: 51–63. Jan 1961.

Friend, D. J. C. The control of chlorophyll accumulation in leaves of Marquis wheat by temperature and light intensity II. Chlorophyll contents relative to leaf area and thickness. Physiol. Plant. **14**: 28–39. 1961.

Fritschen, Leo J. & Shaw, R. H. Transpiration and evapotranspiration of corn as related to meteorological factors. Agron. Jour. **53**: 71–74. Apr 1961.

Gadebusch, Hans H. & Johnson, John D. Specific degradation of *Cryptococcus neoformans* 3723 capsular polysaccharide by a microbial enzyme. I. Isolation, partial purification, and properties of the enzyme. Canad. Jour. Microbiol. **7**: 53–60. Feb 1961.

Gardner, F. P. & Kasperbauer, M. J. Seedling emergence and growth responses of dwarf grain sorghum as affected by gibberellic acid. Iowa St. Univ. Jour. Sci. **35**: 311–318. 15 Feb 1961.

Glasziou, K. T. Accumulation & transformation of sugars in stalks of sugar cane. Origin of glucose & fructose in the inner space. Pl. Physiol. **36**: 175–179. Mar 1961.

Gorham, Eville. Chlorophyll derivatives, sulphur, and carbon in sediment cores from two English lakes. Canad. Jour. Bot. **39**: 333–338. 20 Mar 1961.

Gowing, Donald P. Experiments on the photoperiodic response in pineapple. Am. Jour. Bot. **48**: 16–21. 23 Jan 1961.

Gowing, Donald P. & Leeper, Robert W. Studies on the relation of chemical structure to plant growth-regulator activity in the pineapple plant. III. Naphthalene derivatives and heterocyclic compounds. Bot. Gaz. **122**: 179–188. Mar [11 Apr] 1961.

Green, G. J., Johnson, T. & Welsh, J. N. Physiologic specialization in oat stem rust in Canada from 1944 to 1959. Canad. Jour. Pl. Sci. **41**: 153–165 *pl. 1.* Jan 1961.

Habermann, Helen M. Light dependent oxygen metabolism of chloroplast preparations. III. Photooxidation of ascorbic acid. Pl. Physiol. **36**: 252–261. Mar 1961.

Handley, Raymond & Overstreet, Roy. Effect of various cations upon absorption of carrier-free cesium. Pl. Physiol. **36**: 66–69. Jan 1961.

Haskins, F. A. & Downs, S. C. Activities of acid phosphatase, peroxidase, and polyphenolase in etiolated shoots from control and irradiated maize seeds. Agron. Jour. **53**: 90–93. Apr 1961.

Hatfield, D. L., Van Ballen, C. & Forrest, H. S. Pteridines in blue green algae. Pl. Physiol. **36**: 240–243. Mar 1961.

Hesseltine, C. W. & Benjamin, C. R. Microbiological production of carotenoids. VI. Some factors affecting sporulation and growth in the Choanephoraceae. Mycologia **51**: 887–901. 1959 [14 Apr 1961].

Holt, A. Stanley. Further evidence of the relation between 2-desvinyl-2-formyl-chlorophyll-*a* and chlorophyll-*d*. Canad. Jour. Bot. **39**: 327–331. 20 Mar 1961.

Honda, S. I. & Muenster, Anne-Marie. Some effects of tonicity on lupine succinoxidase. Pl. Physiol. **36**: 105–112. Jan 1961.

Howell, Robert W. Changes in metabolic characteristics of mitochondria from soybean cotyledons during germination. Physiol. Plant. **14**: 89–97. 1961.

Hunter, Edward O. & McVeigh, Ilda. The effects of selected antibiotics on pure cultures of algae. Am. Jour. Bot. **48**: 179–185. 15 Feb 1961.

Jacobson, Louis, Hannapel, Raymond J., Moore, David P. & Schaedle, Michail. Influence of calcium on selectivity of ion absorption process. Pl. Physiol. **36**: 58–61. Jan 1961.

Jacobson, Louis, Hannapel, Raymond J., Schaedle, Michail & Moore, David P. Effect of root to solution ratio in ion absorption experiments. Pl. Physiol. **36**: 62–65. Jan 1961.

Johanson, N. G. & Muzik, T. J. Some effects of 2,4-D on wheat yield root growth. Bot. Gaz. **122**: 188–194. Mar [11 Apr] 1961.

Johnson, G. T. & Dixon, G. J. Oxygen-uptake studies on glucose-grown and fatty-acid-exposed fungus cells. Mycologia **51**: 647–655. 1959 [17 Mar 1961].

Kersting, J. F., Pauli, A. W. & Stickler, F. C. Grain sorghum caryopsis development: II. Changes in chemical composition. Agron. Jour. **53**: 74–77. Apr 1961.

Key, Joe L. & Hanson, John B. Some effects of 2,4-dichlorophenoxyacetic acid on soluble nucleotides & nucleic acid of soybean seedlings. Pl. Physiol. **36**: 145–152. Mar 1961.

Klein, Attila O. & Hagen, Charles W. Anthocyanin production in detached petals of *Impatiens balsamina* L. Pl. Physiol. **36**: 1–9. Jan 1961.

Klingensmith, M. J. The effect of certain benzazole compounds on plant growth and development. Am. Jour. Bot. **48**: 40–45. 23 Jan 1961.

Krall, A. R., Good, N. E. & Mayne, B. C. Cyclic and non-cyclic photophosphorylation in chloroplasts distinguished by use of labeled oxygen. Pl. Physiol. **36**: 44–47. Jan 1961.

Krotkov, G. G. H. Duff memorial symposium on developmental physiology. Introductory remarks by the chairman. Canad. Jour. Bot. **39**: 439–440. 20 Mar 1961.

Kupila, Sirkka, Bryan, A. M. & Stern, Herbert. Extractability of DNA & its determination in tissues of higher plants. Pl. Physiol. **36**: 212–215. Mar 1961.

Kupila, Sirkka & Stern, Herbert. DNA content of broad bean (*Vicia faba*) internodes in connection with tumor induction by *Agrobacterium tumefaciens*. Pl. Physiol. **36**: 216–219. Mar 1961.

Lochhead, A. G. & Cook, F. D. Microbial growth factors in relation to resistance of flax varieties to *Fusarium* wilt. Canad. Jour. Bot. **39**: 7–19. 25 Jan 1961.

Lovett, J. S. & Cantino, E. C. Reversible bicarbonate-induced enzyme activity and the point of no return during morphogenesis in *Blastocladiella*. Jour. Gen. Microbiol. **24**: 87–93. Jan 1961.

Lunt, O. R. & Kofranek, A. M. Exploratory nutritional studies on Cymbidiums using two textures of fir bark. Am. Orchid Soc. Bull. **30**: 297–302. Apr 1961.

Lyon, Charles J. Measurement of geotropic sensitivity of seedlings. Science **133**: 194, 195. 20 Jan 1961.

McLeod, G. C. Action spectra of light-saturated photosynthesis. Pl. Physiol. **36**: 114–117. Jan 1961.

McLeod, G. C. Variation of enhancement of photosynthesis with conditions of algal growth. Science **133**: 192, 193. 20 Jan 1961.

Marini, F., Arnow, P. & Lampen, J. O. The effect of monovalent cations on the inhibition of yeast metabolism by nystatin. Jour. Gen. Microbiol. **24**: 51–62. Jan 1961.

Mauney, J. R. The cultures in vitro of immature cotton embryos. Bot. Gaz. **122**: 205–209. Mar [11 Apr] 1961.

Mertz, Dan & Levitt, J. The relation between ion adsorption on the cell wall and active uptake. Physiol. Plant. **14**: 57–61. 1961.

Michel, Burlyn E. Further studies of synergism in slit pea test. Pl. Physiol. **36**: 92–98. Jan 1961.

Miller, John H. & Miller, Pauline M. The effect of different light conditions and sucrose on the growth and development of the gametophyte of the fern, *Onoclea sensibilis*. Am. Jour. Bot. **48**: 154–159. 15 Feb 1961.

Moore, David P., Jacobson, Louis & Overstreet, Roy. Uptake of calcium by excised barley roots. Pl. Physiol. **36**: 53–57. Jan 1961.

Mortimer, D. C. Some observations on the formation of glyceric acid during photosynthesis experiments. Canad. Jour. Bot. **39**: 1–5. 25 Jan 1961.

Muir, Robert M., Hansch, Corwin & Galley, Joseph. Thiocarbamates as plant growth regulators. Pl. Physiol. **36**: 222–225. Mar 1961.

Näf, Ulrich. Mode of action of an antheridium-inducing substance in ferns. Nature **189**: 900–903. 18 Mar 1961.

Naylor, J. M. & Simpson, G. M. Dormancy studies in seed of *Avena fatua*. 2. Gibberellin-sensitive inhibitory mechanism in the embryo. Canad. Jour. Bot. **39**: 281–295. 20 Mar 1961.

Niederpruem, Donald J. & Hackett, David P. Cytochrome system in *Schizophyllum commune*. Pl. Physiol. **36**: 79–84. Jan 1961.

Ormrod, D. P. Photosynthesis rates of young rice plants as affected by light intensity and temperature. Agron. Jour. **53**: 93–95. Apr 1961.

Osborne, Daphne J. & McCalla, D. R. Rapid bioassay for kinetin & kinins using senescing leaf tissue. Pl. Physiol. **36**: 219–221. Mar 1961.

Ovington, J. D. Some aspects of energy flow in plantations of *Pinus sylvestris* L. Ann. Bot. II. **25**: 12–20. Jan 1961.

Park, Roderic & Epstein, Samuel. Metabolic fractionation of C^{13} & C^{14} in plants. Pl. Physiol. **36**: 133–138. Mar 1961.

Peterson, E. A. Observations on the influence of plant illumination on the fungal flora of roots. Canad. Jour. Microbiol. **7**: 1–6. *pl. 1.* Feb 1961.

Plaisted, Phillip H. The presence of sedoheptulose in *Coleus blumei* Benth. Contr. Boyce Thompson Inst. **21**: 35, 36. Jan–Mar 1961.

Quick, Clarence R. & Quick, Alice S. Germination of *Ceanothus* seeds. Madroño **16**: 23–30. 20 Jan 1961.

Rasmussen, G. K. & Smith, P. F. Effects of calcium, potassium & magnesium on oxalic, malic, & citric acid content of Valencia orange leaf tissue. Pl. Physiol. **36**: 99–101. Jan 1961.

Rohringer, R. & Heitefuss, R. Incorporation of P^{32} into ribonucleic acid of rusted wheat leaves. Canad. Jour. Bot. **39**: 263–267. 20 Mar 1961.

Romberger, John A. & Norton, Grenville. Changing respiratory pathways in potato tuber slices. Pl. Physiol. **36**: 20–29. Jan 1961.

Row, Vas V., Sanford, William W. & Hitchcock, A. E. Indole-3-acetyl-D,L-aspartic acid as a naturally-occuring indole compound in tomato seedlings. Contr. Boyce Thompson Inst. **21**: 1–10. Jan–Mar 1961.

Sarin, M. N. Physiological studies on salt tolerance of crop plants XV. Influence of sodium sulfate on chemical composition of *Cicer arietinum* seedlings. Lloydia **23**: 65–71. Sep 1960 [8 Mar 1961].

Schmid, Walter E. & Gerloff, Gerald C. A naturally occuring chelate of iron in xylem exudate. Pl. Physiol. **36**: 226–231. Mar 1961.

Setterfield, George. Structure and composition of plant-cell organelles in relation to growth and development. Canad. Jour. Bot. **39**: 469–489. *pl. 1–5.* 20 Mar 1961.

Sheehan, Thomas J. Effects of nutrition and potting media on growth and flowering of certain epiphytic orchids. Am. Orchid Soc. Bull. **30**: 289–292. Apr 1961.

Shuel, R. W. Influence of productive organs on secretion of sugars in flowers of *Streptosolen jamesonii* Miers. Pl. Physiol. **36**: 265–271. Mar 1961.

Sisler, Edward C. & Klein, William H. Effect of red and far red irradiation on nucleotide phosphate and adenosine triphosphate levels in dark-grown bean and *Avena* seedlings. Physiol. Plant. **14**: 115–123. 1961.

Sorokin, Constantine. Effects of illuminance near and below light saturation on the time course of photosynthesis in synchronized cultures of algae. Jour. Exp. Bot. **12**: 56–64. Feb 1961.

Sorokin, Constantine. Time course of oxygen evolution during photosynthesis in synchronized cultures of algae. Pl. Physiol. **36**: 232–239. Mar 1961.

Steward, F. C. Vistas in plant physiology: Problems of organization, growth, and morphogenesis. Canad. Jour. Bot. **39**: 441–460. *pl. 1–3.* 20 Mar 1961.

Stifler, Richard Bond. Growth of sporangiophores of *Phycomyces* immersed in water. Science **133**: 1022. 31 Mar 1961.

Sudia, T. W. & Linck, A. J. The effect of pH on the absorption of Sr^{89}, P^{32}, and Fe^{59} ions by leaves of *Zea mays*. Ohio Jour. Sci **61**: 107–112. 28 Mar 1961

Taper, C. D. & Leach, W. Note on the effects of calcium concentration in culture solutions upon the leaf and whole plant absorption of iron and manganese by dwarf kidney bean. Canad. Jour. Bot. **39**: 437, 438. 20 Mar 1961.

Takahashi, Nobutaka & Curtis, Roy. W. Isolation and characterization of malformin. Pl. Physiol. **36**: 30–36. Jan 1961.

Thames, John L. Effects of wax coatings on leaf temperatures & field survival of *Pinus taeda* seedlings. Pl. Physiol. **36**: 180–182. Mar 1961.

Thomson, Betty F. & Miller, Pauline Monz. Growth patterns of pea seedlings in darkness and in red and white light. Am. Jour. Bot. **48**: 256–261. Mar [28 Feb] 1961.

Todd, Glenn W., Bean, Rossi C. & Propst, Betty. Phytosynthesis and respiration in developing fruits. II. Comparative rates at various stages of development. Pl. Physiol. **36**: 69–73. Jan 1961.

Townsend, G. Fred. Photoreactivation by colored light of ultraviolet inactivated yeast cells. Trans. Am. Micr. Soc. **80**: 70–73. Jan 1961.

Wallace, A. & Mueller R. T. Cyanide & chelating agent effects on in vitro CO_2 fixation in sweet orange leaves. Pl. Physiol. **36**: 118–120. Jan 1961.

Wallihan, Ellis F. Effect of sodium bicarbonate on iron absorption by orange seedlings. Pl. Physiol. **36**: 52, 53. Jan 1961.

Ward, E. W. B. & Henry, A. W. Comparative response of two saprophytic and two plant parasitic soil fungi to temperature, hydrogen-ion concentration, and nutritional factors. Canad. Jour. Bot. **39**: 65–79. 25 Jan 1961.

Watkins, G. M. Physiology of *Sclerotium rolfsii*, with emphasis on parasitism [Symposium on *Sclerotium rolfsii*]. Phytopathology **51**: 110–113. 20 Feb 1961.

Westlake, D. W. S. & Simpson, F. J. Degradation of rutin by *Aspergillus flavus*. Factors affecting production of the enzyme system. Canad. Jour. Microbiol. **7**: 33–44. Feb 1961.

Wetherell, D. F. Culture of fresh water algae in enriched natural sea water. Physiol. Plant. **14**: 1–6. 1961.

Woltz, S. S. & Jackson, C. R. Production of yellow strapleaf of *Chrysanthemum* & similar disorders by amino acid treatment. Pl. Physiol. **36**: 197–201. Mar 1961.

Woolley, Joseph T. Mechanisms by which wind influences transpiration. Pl. Physiol. **36**: 112–114. Jan 1961.

Wort, D. J. & Loughman, B. C. The effect of 3-amino-1,2,4-triazole on the uptake, retention, distribution, and utilization of labelled phosphorus by young barley plants. Canad. Jour. Bot. **39**: 339–351. 20 Mar 1961.

Younger, Victor B. Low temperature induced male sterility in male-fertile *Pennisetum clandestinum*. Science **133**: 577, 578. 24 Feb 1961.

Zabka, George G. Photoperiodism in *Amaranthus caudatus*. I. A re-examination of the photoperiodic response. Am. Jour. Bot. **48**: 21–28. 23 Jan 1961.

Zimmerman, Martin H. Movement of organic substances in trees. Science **133**: 73–79. 13 Jan 1961.

Zweig, Gunter & DeVay, J. E. On the biosynthesis of gibberellins from carbon-14-substrates by *Fusarium moniliforme*. Mycologia **51**: 877–886. 1959 [14 Apr 1961].

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(including biography and nomenclature)

Blake, S. F. Edward Palmer's visit to Guadalupe Island, Mexico, in 1875. Madroño **16**: 1–4. 20 Jan 1961.

Broyer, T. C. John Wesley Shive, 1877–1960. Pl. Physiol. **36**: 125, 126. Jan 1961.

Brunel, Jules. Frère Irénée-Marie (1889–1960). Nat. Canad. **88**: 5–8. Jan 1961.

Correll, Donovan S. Ivan Murray Johnston (1898–1960). Taxon **10**: 1–8. Jan 1961.

French, Richard. Liberty Hyde Bailey. Jour. Calif. Hort. Soc. **22**: 20–24. Jan 1961.

Howard, Richard A. Ivan Murray Johnston, 1898–1960. Jour. Arnold Arb. **42**: 1–9. *port.* Jan 1961.

Mohlenbrock, Robert H. A decade of botanizing in Illinois. Rhodora **61**: 19–24. 26 Jan 1961.

Monteiro Neto, Honório da Costa. Da espécie. Arq. Serv. Flor. Rio de Janeiro **11**: 175–221. 1957.

Muir, Robert M. Walter Ferdinand Loehwing, 1896–1960. Pl. Physiol. **36**: 126, 127. Jan 1961.

Robbins, W. Rei. John Wesley Shive. Bull. Torrey Club **87**: 417–419. 15 Dec 1960.

Schwarten, Lazella. Bibliograhpy. *In:* Howard, Richard A. Ivan Murray Johnston, 1898–1960. Jour. Arnold Arb. **42**: 4–9. Jan 1961.

Steere, William Campbell. Botanical problems in arctic America. Gard. Jour. N. Y. Bot. Gard. **11**: 1–5. Jan–Feb 1961.

Stevenson, John A. Rolla Kent Beattie, 1875–1960. Phytopathology **51**: 136. 15 Mar 1961.

Walker, Egbert H. References to dates of issue and other bibliographic data on entries in the Merrill-Walker: "Bibliography of eastern Asiatic botany" 1938. Taxon **10**: 45–49. Feb 1961.

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